London, John Weale, 1852.

THE

RUDIMENTS

OF

CIVIL ENGINEERING,

BY HENRY LAW,

CIVIL ENGINEER;

AND

THE RUDIMENTS

OF

HYDRAULIC ENGINEERING,

BY G. R. BURNELL,

CIVIL ENGINEER.

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THE RUDIMENTS

OF

CIVIL ENGINEERING.

PART III.

SPECIAL CONSTRUCTION.

The Charing Cross Suspension Bridge.

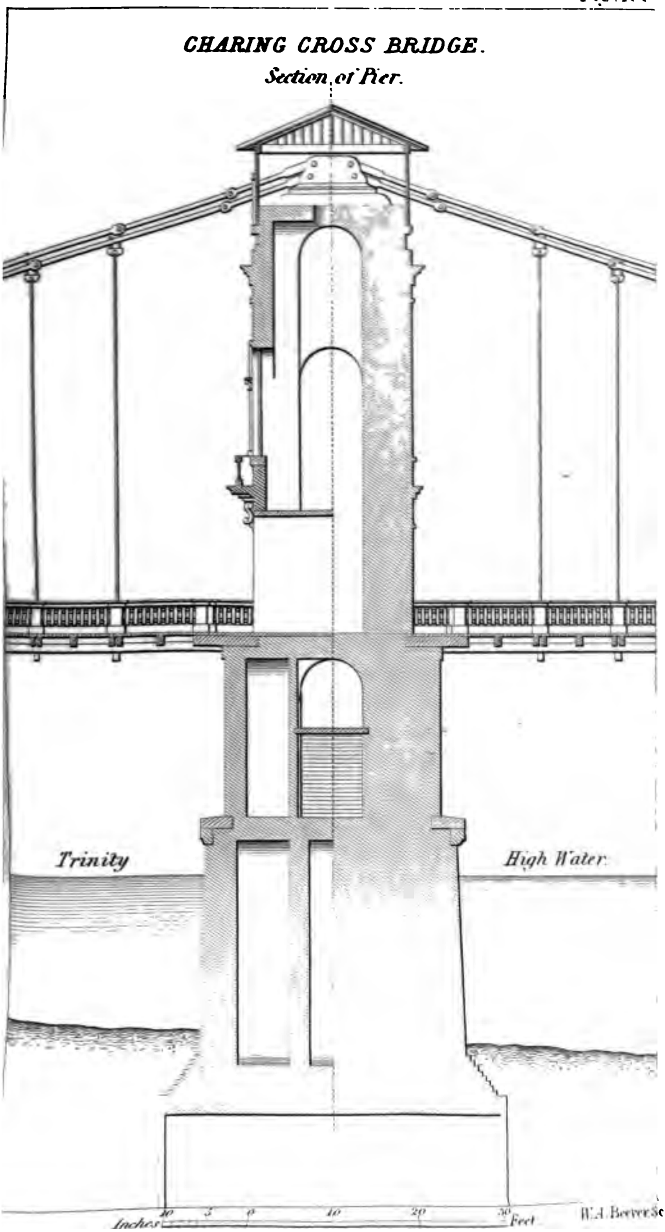
THE Charing Cross Suspension Bridge, which has lately been constructed over the Thames by Mr. Brunel, has been selected, as affording one of the latest and by far the best example which could be found of this kind of bridge.

The general dimensions of this bridge have been given in the table at page 147 of the Second Part; and the details of its construction are exhibited in the accompanying plates, figs. 105 to 118. It has been explained in the First Part*, that in order that the chains of a suspension bridge should be equally strained throughout, their sectional area should vary according to the inclination of the chain, being greatest at the piers, where the chains are most inclined, and least in the center, where they are horizontal. Charing Cross Bridge is, however, the only one of all those mentioned in the table which has the area of its chains thus varied, according to the varying strain; in all the others the chains are parallel, or of equal sectional area throughout; but in the case of the Charing

* Page 60.

Cross Bridge, the chains vary from 296 square inches in the center to 312 square inches near the piers.

The bridge consists of three openings, that in the center, which has a span of 676·5 feet, forming a complete catenary, and the two side ones, which are each 339·9 feet, forming semi-catenaries. The superstructure of one of the piers is shown in elevation in fig. 105; and fig. 106 is a transverse section upon the line C D E F, fig. 109, of one of the piers entire, affording also a longitudinal section of a portion of the platform, a transverse section of which is shown in the previous figure; a longitudinal section of the lower portion of the pier is given in fig. 107, and a sectional plan of the same in fig. 108; while fig. 109 exhibits two horizontal sections of the superstructure of the piers, that on the right hand being taken through the basement below the platform, and that on the left hand through the pier above the same. From these it will be seen that the whole of the pier is constructed upon the principle which we advocated for those of all kinds of bridges, namely, that of being formed hollow, in such a manner as to combine the requisite size of base to insure stability, with as little weight as possible. Had the piers of this bridge been built solid, instead of as they have been, their weight would have been increased in the proportion of 1 to 1·7. By an examination of the sections, figs. 106 and 109, it will be seen that the weight of the chains is received and transmitted to the lower part of the pier by four square pillars or piers of brickwork, each side of which is 7 feet 3 inches, and which form the angles or corners of the campanile tower. These piers are steadied and connected together by the walls of the same, except where the latter are pierced to form windows or doorways. Below the platform the dimensions of these piers are somewhat increased, as shown in the right-hand half of the sections, figs. 106 and 109. The foundation of these piers below the basement is formed by a solid mass of brickwork, 7 feet 6 inches wide, running entirely across the piers, as shown in figs. 107 and



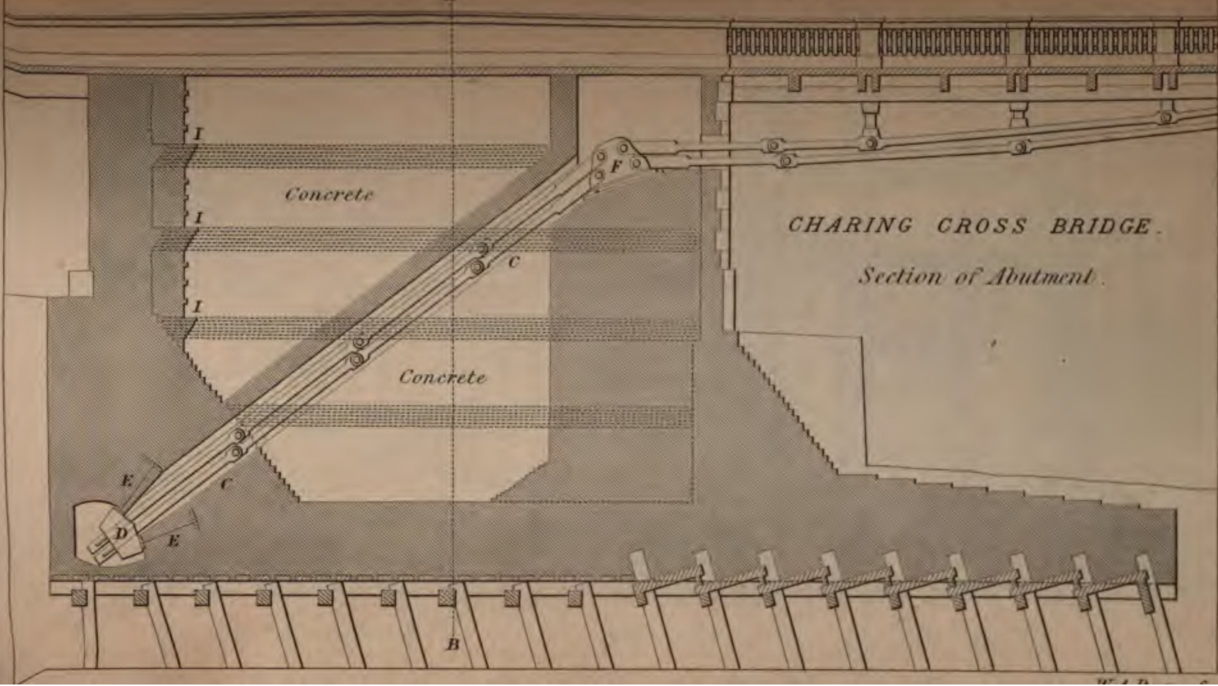
London, John Weale, 1852.

It will be seen, by a reference to fig. 113, that the chain where it enters the abutment is nearly horizontal, and, therefore, so is also the direction of the strain which it produces, tending to pull the abutment forwards into the river. This tendency is, however, counteracted in a great degree by the very judicious manner in which the piles are arranged. In the abutment of an ordinary bridge it is usual to make the piles slope towards the arch, so as to receive its thrust nearly perpendicularly; in this case, however, the nature of the strain is quite different, and, were the piles driven in the ordinary manner, they would have offered but comparatively a slight resistance. In this case, therefore, they have been made to slope in the contrary direction, or away from the river, as shown in the section 113, so that the abutment cannot move forwards, in the direction in which the chains solicit it, without forcing every pile to move in the same direction, and consequently to assume a less inclined position, in doing which, as they may be supposed to turn upon their lower extremity as a center, it is obvious that they would have to lift or raise the whole mass of the abutment bodily, which would require an enormous force, in addition to that necessary to overcome the resistance which the ground would oppose to the motion of the piles, by its pressure against their front surfaces.

As, therefore, the weight of the abutment in this case adds to its stability, it was formed nearly of one solid mass; but as the cost of so large a quantity of brickwork would have been very considerable, it was formed hollow, as shown in the sections, figs. 113 and 114, and the spaces thus left were filled in with concrete. The space in which the north abutment had to be built being limited by the proximity of the Hungerford Market, the piles were carried out beneath the level of the shore in front of the abutment, as shown in fig. 113, the pressure being distributed over them by the manner in which the brickwork was stepped down.

Before explaining the manner in which the main chains were secured to the abutments, it will be well to describe the

Fig. 113.


CHARING CROSS BRIDGE.
Section of Abutment.
Concrete
Concrete
A
B
C
C
D
E
E
F
I
I
I

CHARING CROSS BRIDGE.

Details of Saddle.

Fig. 115.a

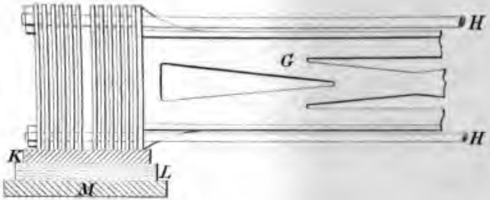
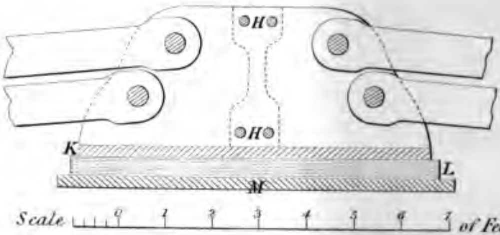
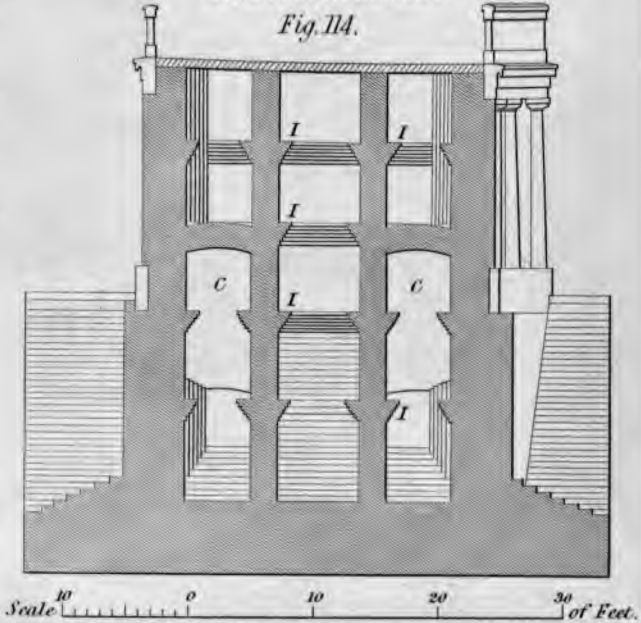


Fig. 115.b



Section of Abutment.

Fig. 114.



Details of the Chains.

Fig. 110.

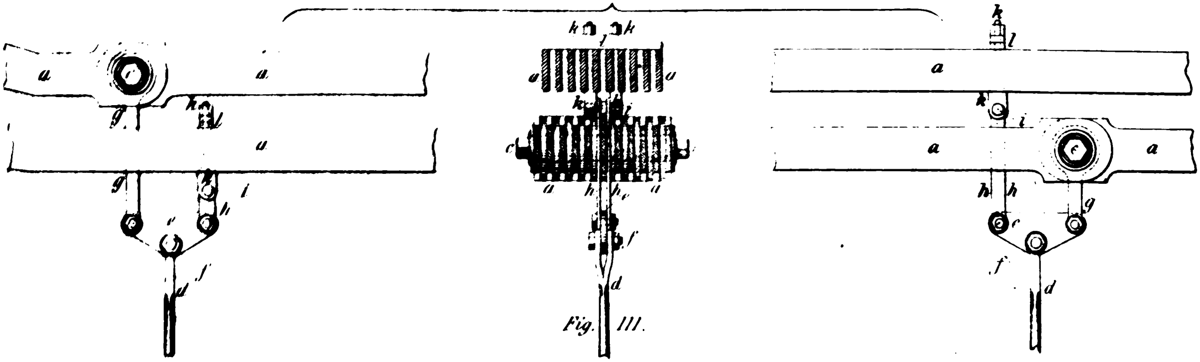
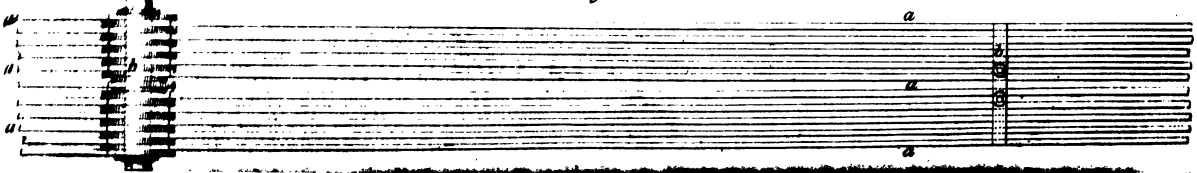


Fig. 111.

Fig. 112.



chains themselves. By an inspection of fig. 104, it will be seen that there are four separate chains, two on either side of the platform, being placed one above the other, and having the suspending rods by which the roadway is supported connected with both chains, in such a manner that each receives an equal portion of its strain. Fig. 110 is a side view of a short portion of one pair of chains, broken in the middle to afford space for the transverse section of the same, fig. 111; and fig. 112 is a plan of the upper chain. Each chain consists of ten and eleven links alternately; these, *a a*, are of wrought iron, 7 inches in depth, and of such a thickness (about an inch) as to give the requisite sectional area, which, as already stated, varies with the inclination of the chain. These links are terminated at each end by an enlarged part, through which an eye or hole for the reception of the coupling pin was drilled, the distance apart of the centers of the two holes being exactly 24 feet. The links of one portion of the chain being arranged parallel to each other, with their eyes in the same straight line, and with about an inch space between them, those of the adjoining portion of the chain are introduced between them, so as to bring the eyes of the latter in the same straight line with those of the former, when a wrought-iron pin, *b*, $4\frac{5}{8}$ inches in diameter, is passed through them, and the chains are thus securely connected and coupled together; the pins are prevented from falling out by a cast-iron nut, *c*, screwed on to each end, as shown in the figures. This method of connecting the chains is a great improvement upon that which had always previously been employed, and which consisted in having the same number of links in every portion of the chain, and connecting them together by means of short coupling links; in this arrangement two pins were required at every joint, and consequently double the number which were employed by the arrangement here adopted. The links, as before stated, are 24 feet in length; but the chains are so arranged that the joints of the upper chain are precisely midway between those

of the lower one, and as the suspending rods are attached to every joint, their distance apart is only 12 feet, as shown in fig. 106. Every one of these suspending rods is attached *to both* chains in the following manner: the end of the rod *d* is formed with a forked head (as shown in fig. 111), which embraces the lower part of a triangular piece of wrought iron, *e*, with which it is connected by a pin, *f*. This triangular piece is supported at each end by two small links, *g g* and *h h*; the former have eyes of sufficient size to admit the coupling pin, *b*, of the main chains, and are placed between the two center links of the same, the pin, *b*, passing through them, as shown in figs. 111 and 112; the latter, *h h*, are secured by the pin, *i*, to two short bolts, *k k*, passing through an iron bar, *l*, which lies across the whole of the links of the other chain, and by means of which they are all made to receive a uniform weight. The pin *f* being exactly midway between the points of attachment of the links *g* and *h*, the weight of the suspending rod, *c*, and its load, is equally divided between them, and therefore between the two chains to which they are connected.

We will now describe the manner in which the main chains are secured to the abutments. They approach it nearly horizontally, as shown in fig. 113, in which direction they proceed for about 10 feet, after which they are made to dip at about an angle of 37 degrees, passing down through two tunnels, C C, to the lower part of the back of the abutments, where they are securely held by strong keys, driven through mortised holes in the ends of the links, and which bear against twelve plates, D, placed between the links, and resting against two cast-iron girders, E E, firmly built into the solid brickwork. At the point where the direction of the chains is altered, both chains are connected to deep links, F, the bottoms of which are flat, and rest upon a cast-iron plate, K, as shown upon a larger scale in figs. 115*a* and 115*b*, forming a kind of saddle. Between the brickwork and these cast-iron bed plates a layer of several thicknesses of felt dipped in

CHARING CROSS BRIDGE.

Details of Saddle.

Fig. 115.a

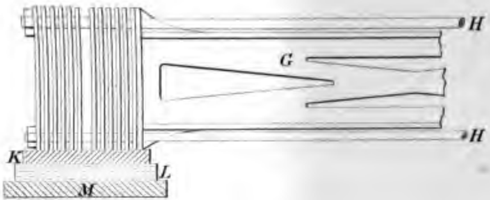
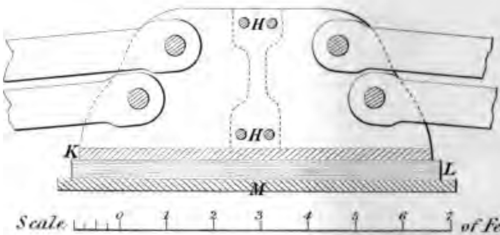
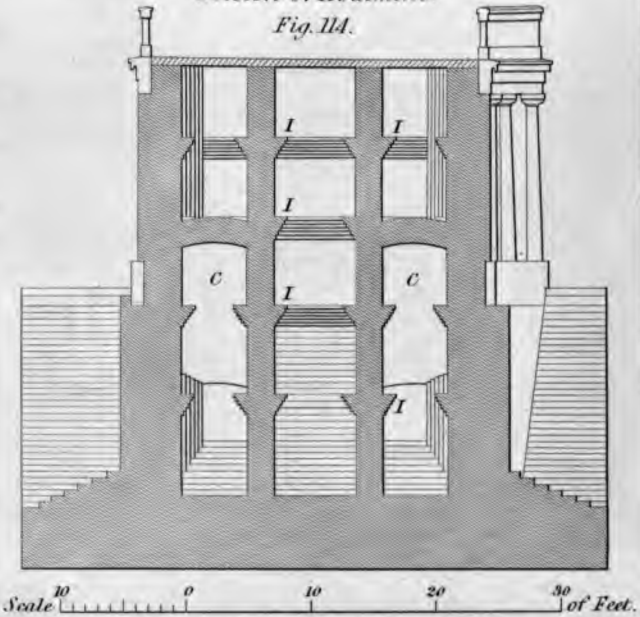


Fig. 115.b



Section of Abutment.

Fig. 114.



Beever Sc.

Fig. 125.

be the same as that of the shaft, and its breadth may be made greater, as shown in the figures, so as to project into the ground and assist in supporting the structure. As the curb becomes a part of the permanent work, it should be of oak or elm timber of the best quality.
The curb being placed, the wall or lining (B B) of th
should be proceeded with, especial care being taken to
the ground firmly on the outer side, so as to leave no s
vacuity: indeed it is impossible, in all operations in
and other subterranean works, to pay too much atten
prevent the slightest vacuity between the work and the g
but, on the contrary, whenever the ground is at all loose
posed to move, every inch of surface should be well sup
and not only supported, but well strutted against, s
maintain an active pressure at all times against it.
as the brickwork forming the lining has been carried u
level of the ground, and the earth securely rammed or
in behind it, the excavation for a second length may
ceeded with. This, however, must be done with caut
as not to endanger the stability of the portion already b
undermining its foundation. We must first carry do
excavation in the center of the interior of the shaft,
sufficient ground under the curb safely to support it;
then cautiously remove the ground from under the curb
opposite points, leaving the intermediate ground to for

Fig. 126.

support. The or recesses thus ed afford the of introducing or props for the ry support of the ile the remainder ground is being l. These props be placed in an position, as t c c c, fig. 126, ot to be in the he second curb; uld be spiked to r curb, to secure om slipping out , and should rest lower extremity upon a broad sole piece, D D D, to pre- ir sinking into the ground. The props having been ed, the remainder of the ground may be removed, a urb, similar in every respect to the former, laid at the f the excavation, and the lining of brickwork proceeded the spaces between the timber struts, in the manner i fig. 126. Upon the brickwork being brought up to r side of the first curb, great care should be taken in filling up the space, so that the curb may have a firm re bed upon the brickwork below it. The props or ay then be removed, and the brickwork completed in es which they had occupied. The excavation should proceeded with, and the various operations already l repeated until the shaft has attained the required The mode of building shafts which has just been l is technically termed *underpinning*.

econd method is frequently employed in sinking wells, t always be adopted when the soil is too loose or full

Fig. 127.

of water to allow of an open excavation being made with safety. It consists in forming the curb as shown at A A, fig. 127, with a sharp edge or rim, instead of having a broad flat surface, as in the former case; upon this curb the brickwork of the shaft is to be built as before until carried up to the level of the surface. The excavation within the shaft is then to be proceeded with, the whole of the ground being in tl removed from under the curb, which, being thus left v support, and being loaded with the weight of the bri upon it, will gradually descend; and thus, as the excava carried down, the curb will follow, and as it sinks tl must be carried up, so as to maintain it level with the of the ground. The principal care required in this r sinking shafts is, to avoid one side of the curb descendin rapidly than the opposite one, by which the shaft wo thrown out of the perpendicular, and so much resistanc sioned as possibly to prevent its further descent. By management, however, in the removal of the groun beneath the curb, this may be usually avoided; and earth-bound, the shaft may frequently be set free ag pouring water around it, so as to soften the ground outer side. A very good precaution against a shaft be earth-bound, is, to build it slightly tapering upward tapering, however, should not be too considerable, otl the space left around it by the descent of the shaft wo sufficient to loosen and dislocate the surrounding groun

The brick shaft having, by one or other of these been carried down to within a few feet of the top of t tended tunnel, the excavation should then be cau

proceeded with, the sides being secured with timber framing and planks, until carried below the level of the bottom of the tunnel. Particular care should be taken that no movement in the ground takes place, because the difficulty of forming the tunnel would be greatly increased if the ground through which it had to be formed had been previously disturbed. The manner of securing the lower portion of the excavation with timber is shown in figs. 128 and 129, the former being a vertical, and the

Fig. 128.

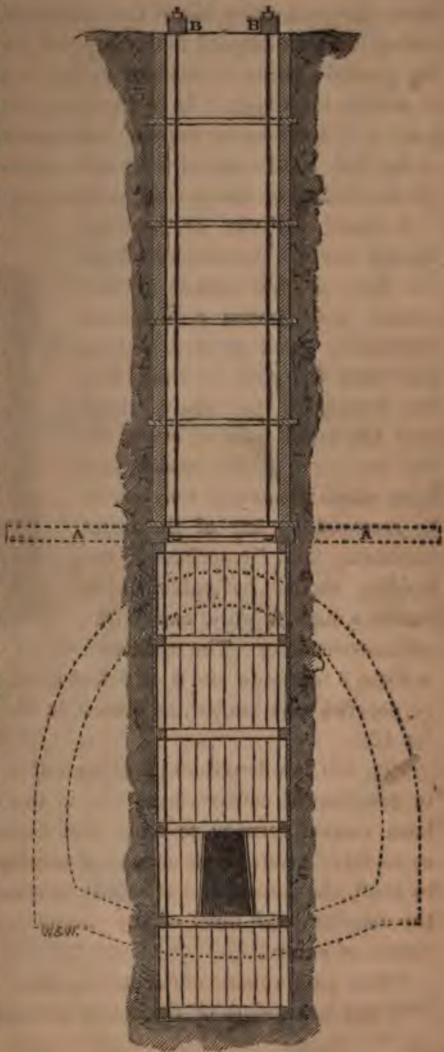


Fig. 129.

latter a horizontal section. Previously, however, to
down the excavation below the brickwork of the sha
means must be adopted for its support, as the mere fr
the ground against its exterior surface would not be s
to sustain its weight. It is therefore necessary either
port it by introducing timbers underneath it, as show
in fig. 128, or to suspend it by rods secured to timbers
on the surface of the ground, as shown at B B.

Fig. 130

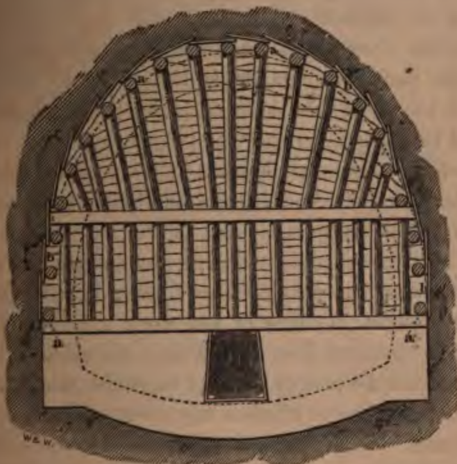
A small driftway or heading should now be commenced about the level of the bottom of the tunnel, and having a sufficient inclination given to it to enable any water met with to drain into the bottom of the shaft, which thus becomes a well or sumpt for the drainage of the works, and from which the water may easily be removed by any of the usual methods. The dimensions of the heading should be sufficient to enable a man to work in it without inconvenience. The usual size
s about 3 feet wide and 5 or 6 feet in height; its side
be secured with timber, as shown in the transverse
fig. 130.

Fig. 131 is a longitudinal section of a portion of
in progress of construction. C, is the driftway, wh
been carried forward to meet that from the next s
as to form a continuous means of communication fro
to shaft, the importance of which is considerable in
the direction and level of the tunnel to be set out
chance of error.

These preliminary works having been completed,
form and dimensions of the tunnel determined, the ex

Fig. 131.

Fig. 132.



for it must be commenced, the ground being supported by means of timber and planks in the manner shown in figs. 131

and 132. The longitudinal timbers, *a a*, are termed b the transverse planks, *b b*, *polings*. The length thus e at a time must depend upon the quality of the grou as it is always desirable that the surface of the groun be exposed to the atmospheric influence for as short a possible, it is not proper to proceed too far before i the brickwork.

To insure the brickwork of the tunnel being true curved templates are used for the invert and sides, v upper portion is turned upon a center similar to t ployed for turning the arches of bridges. As the b proceeds, the bars and polings must be carefully remo any vacuity thus left must be filled with earth well in, so as to prevent any settlement of the ground, whi occasion unequal strains upon the body of the tunnel most strata some amount of settlement will take pla superincumbent ground before the brickwork can b the timber and polings should be placed a few inch the top of the tunnel.

As soon as a length of brickwork has been got in side of the shaft, the temporary timber work of t portion of the shaft should be carefully removed, th excavated to the true form of the tunnel, and the b introduced, being securely bonded with and connecte already built on either side, and the brickwork of t being carried down to meet that of the tunnel. W has been properly effected, much of the danger and of the work may be considered as having been surn The excavation of the face of the work must then ceeded with, the top and as much of the sides of t being supported by polings as may be found necessa cial care being taken to prevent any disruption or m of the ground. When the faces of the two opposite v approach within a short distance of each other, great is necessary to avoid the thin partition of ground be turbed. When sandy or other loose strata containin

ties of water are met with, peculiar precautions must en to prevent the loose ground being washed in with ter, which would occasion cavities to be left in the sur- ng ground; it would, however, be equally dangerous to ack and confine the water, and therefore such means e resorted to as will permit the water to percolate into rk, but prevent the ground being brought with it: a mple and effectual mode, under ordinary circumstances, hrust straw into any opening from whence muddy water d to proceed.

n the completion of the tunnel it is desirable that the should be kept open, to afford light and the means of tion; but, in order to avoid accidents, it is advisable to p the brickwork to a height of 8 or 10 feet above the of the ground, and to cover the opening or mouth strong iron grating.

uld the strata through which the tunnel has been con- d contain much water, a certain portion will be found etrate the brickwork, however carefully built, and in case a small drain or culvert should be formed along ter or lowest part of the invert.

Mode of constructing subaqueous Tunnels.

shall now proceed to describe generally the mode d in the construction of the tunnel under the Thames n Rotherhithe and Wapping. The form of the tunnel e understood by a reference to fig. 133, from which it seen that the external form is rectangular, the reason ich was, that the strata being horizontal, and, from their ity to the river, subjected to constantly varying pres- t was considered that a circular structure would have xposed to very irregular strains. The archway was louble, in order that carriages might not have to meet ss in the same opening, and the center or partition wall rmed was pierced with frequent arches, as shown in the

Fig. 133.

longitudinal section, fig. 134, which serve as a means of
munication between the two archways, and form a
pleasing architectural feature in the tunnel.

The external dimensions of the excavation are—in h

Fig. 134.

2 feet 3 inches, and in breadth 37 feet 6 inches; its total length is about 1200 feet. The height of the archway is 17 feet, and the width of each on the springing line 14 feet; the upper portion is semicircular in form, and the side walls and invert segmental. The tunnel is built principally in half-brick rings, the thickness of the brickwork at the crown of the arch being 2 feet 6 inches, and the same below the invert, which is laid upon 3-inch elm planks. The external piers are each 3 feet thick on the springing line, and the center pier is 3 feet 6 inches. The right-hand half of the section, fig. 133, exhibits the mode in which the bricks were arranged when working in 9-inch rings, and the left-hand half when 4½-inch work was employed. The tunnel was built of the hardest picked stock bricks, laid in Roman cement of the best quality, those portions of the work which were most exposed to the action of the water being laid in pure cement, and the other portions in half cement and half pure sharp sand. The bricks for the semicircular arches are made in a wedge form, so as to produce parallel joints.

The section, fig. 133, is taken in the center of the tunnel, in the deepest part, showing the order and position of the various strata met with, as they would have been found if they had not been disturbed; from the constant runs of loose sand and the action of the water, especially on the Wapping side of the river, the strata, however, were usually found considerably dislocated and disturbed. In the section, fig. 133,

a is a stratum of sand, gravel, mud, and river deposits; *b*, a bed of clay, of a reddish-brown colour; *c*, a stratum of clay mixed with silt; *d*, a thin layer of silt very full of shells; *e*, a stratum of stiff blue clay; *f*, a bed of clay of a more mottled character, containing a portion of silt and a number of shells; *g*, a stratum of indurated clay, which at times was so hard as to require wedges to break it up; *h*, a bed of gravel and sand of a green colour; and *i*, a similar stratum, but somewhat coarser.

The tunnel was commenced on the Rotherhithe side of the river in the year 1826, the shaft having been begun early in the previous year. The mode adopted in the sinking of the shaft was similar to that last described, the brickwork being built upon a sharp-edged curb, which descended gradually as the ground was removed from under it. When, however, the shaft had thus been sunk to a depth of 38 feet, it became earth-bound, and, although loaded with a considerable extraneous weight, and the water allowed to rise in the excavation for the purpose of softening the ground, no further movement took place; it was therefore determined to complete it by underpinning in the manner already described, and this, after much trouble and difficulty, arising from the loose nature of the ground, was successfully accomplished. When the shaft was sunk on the opposite or Wapping side of the river, the difficulties which had been encountered in the sinking of the former one were provided against, and the operation so successfully performed that the shaft was sunk to its entire depth (upwards of 72 feet) without becoming at all bound; this was principally owing to the shaft being made larger in diameter at its lower end, and the cast-iron curb being made of great strength.

Our limits will not permit, and the object of the present work does not require, our giving a detailed account of the many casualties and difficulties which were experienced in the course of the work; we shall content ourselves with a general description of the mode in which the tunnel was constructed,

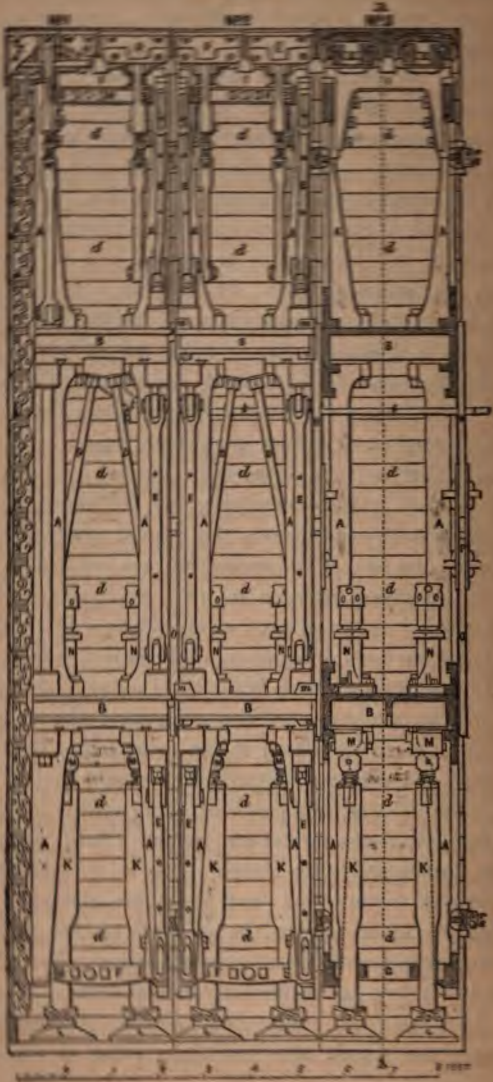
and refer the reader who requires further details to the memoir of the Thames Tunnel in Weale's "Quarterly Papers on Engineering."

The mode of securing the ground already described as being employed in the case of ordinary tunnels, would have been quite inadequate to support the ground and the excessive and constantly-varying pressure occasioned by the river. To meet the special requirements of the case, Sir Isambart Brunel devised a machine, constructed entirely of iron, and so original in its character as to enable him to secure the invention by letters patent. It occupied a space of about 8 feet in advance of the brickwork, and consisted of twelve distinct frames, each about 3 feet in width and 22 feet in height, ranged side by side, like the books on the shelves of a bookcase. Each of these frames was divided vertically into three cells by cast-iron floor-plates, so that the whole shield consisted of 36 cells. The roof and sides were secured by a number of narrow plates of metal, overlapping the portion of the brickwork already built, and entering the ground in advance of the work; while the face of the excavation was secured by timber *polings* so accurately fitted as to leave no aperture whatever through which loose sand or other strata could find their way.

The following brief description of the shield, and the mode of using it, is extracted from Weale's "London Exhibited:"—

"It will at once be seen how admirably the shield was adapted for the duties which it had to perform; the chief of these was, obviously, to support the ground, but a quality equally essential was, the power of being easily advanced or moved forward, as the tunnel progressed. Now, by its division into frames, these two objects were at once attained, for the whole was so contrived that, while six alternate frames were engaged in sustaining the pressure of the ground, the six intermediate frames were relieved entirely from all pressure, and left free to be moved forward without resistance. These, in their turn, then became the pressure-bearers, relieving those which had previously relieved them in a

Fig. 116.



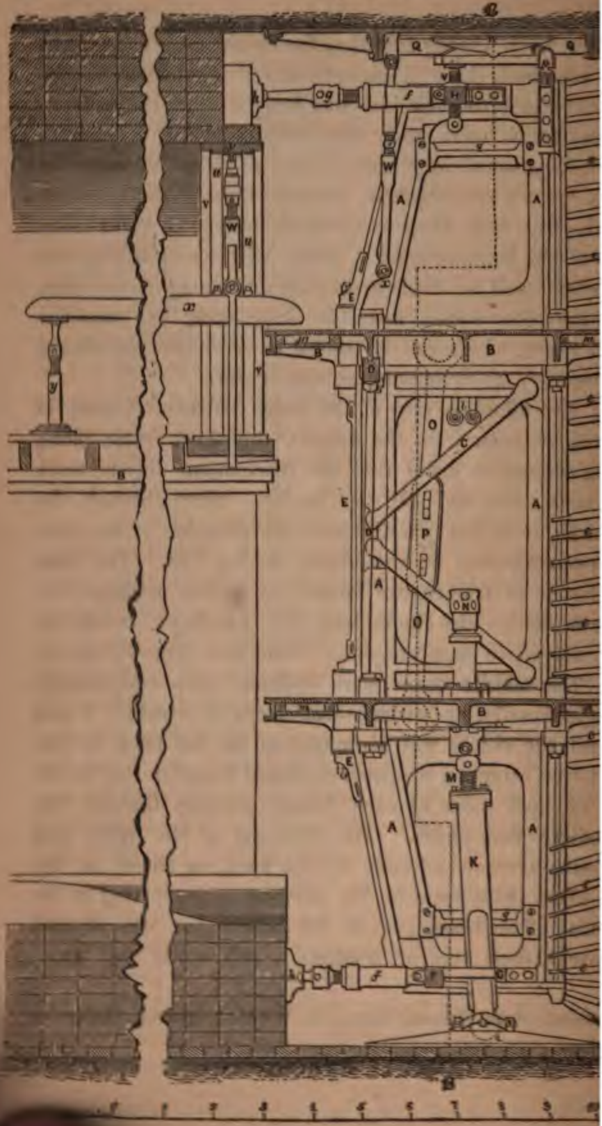
similar manner, and enabling them to be advanced without difficulty.

"'It has been already said that the shield, as first designed by Sir Isambart, bore a considerable resemblance to the worm from which the first idea was derived; but the present shield has much more aptly been compared with a man, to whom, in its general organization, each of these "frames" or divisions bears a resemblance; having legs with both a knee and ankle-joint, with which it alternately steps or walks on in advance of the brick structure; arms, with which it supports and steadies itself, or lends assistance to its neighbours when they require it; and a head, for supporting the superincumbent earth, which can be raised or depressed, or altered in its direction, as circumstances may require.'*

"Fig. 135 affords a view of the three left-hand frames of the shield, as seen from the tunnel, the third frame being shown in section, in order that the mechanism may be more clearly seen; and fig. 136 is a section taken through the same frame, in a line parallel with the direction of the tunnel, or perpendicular to that shown in fig. 135. The sides of the boxes, or frames, are formed by strong castings, A A, securely bolted to the floor-plates, B B, which, as already explained, served to separate every frame into three stories, or boxes. The middle boxes were stiffened, both transversely and longitudinally, by wrought-iron stays or struts, C C and D D; and the shield was strengthened at the back by two wrought-iron straps, E E, which extended from the top to the bottom of both sides of each frame, passing through the intermediate floor-plates. The framings of the upper and lower boxes were sloped away at the back, as shown in fig. 136, to allow more room for the bricklayers in putting in the brickwork. The lower part of the bottom box was secured by a wrought-iron stay or framing, F and G, and the upper

* A Memoir of the Thames Tunnel, in Weale's "Quarterly Papers on Engineering."

Fig. 136.



part of the top box by two similar framings of wrought iron, H and I. Each frame was supported upon two long jack-screws, K K, which, from the duty they had to perform, were termed *legs;* the lower extremities of these jacks rested upon strong wrought-iron plates, L L, termed *shoes*, whose object was, to distribute the weight of the frames, together with the pressure of the superincumbent earth, over a large surface or base; beneath these shoes a flooring of elm planks, 3 inches in thickness, was laid, upon which the brickwork of the tunnel was built, after the ground beneath them had been compressed by the weight of the shield passing over them. The leg was attached to the shoe by a species of ankle-joint, *e*, resembling in principle the method adopted for mounting mariners' compasses, which allowed the shoe to adjust itself readily to any inequality in the ground. At the upper part of the leg was the knee-joint M, about which it turned in the act of stepping forward: the length of the leg could be varied at pleasure, by means of the screw at M, turned by the capstan-head at M, and a second auxiliary one in the middle box, N.

"The frames were also provided with slings, or arms, O, consisting of strong wrought-iron bars, attached at their upper extremities to the floor-plates of the odd-numbered frames, and at their lower extremities to the floor-plates of the even-numbered frames; the attachment consisting in an eye-fitting to a circular pin projecting from the side of the floor-plates, so as to allow a freedom of motion about these pins as a center. The upper and lower extremities of the slings consisted of two separate bars of metal connected by two plates or cheeks, one on either side, through which, and the slings themselves, metal keys or wedges passed, by the tightening up or driving back of which, the length of the slings could be increased or diminished at pleasure. The use of these slings was to enable one frame to *derive* support from its neighbour on either side, or, in its turn, to *afford* support to either of its neighbours. Thus, if one of the odd-numbered frames, in which the upper extremity of the slings were attached to the

top floor-plates, was required to be supported independently of the legs, it was only requisite to tighten up the wedges and lengthen the slings to raise the frame, and relieve the legs entirely from pressure; the slings, in this case, *pushing up* the frame. While, in the case of an even-numbered frame, by driving back the wedges of the slings on either side, and so lessening their length, the frame would be *drawn up*, and the legs relieved from the office of supporting the weight of the frame.

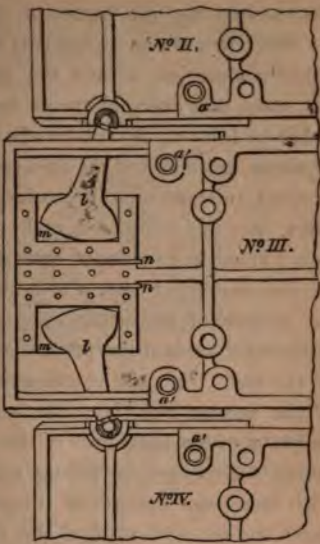
"The ground over the roof of each frame was supported by two plates of metal, Q Q, the tails of which always overlaid the brickwork, as shown in fig. 136, and the points entered the ground some distance in advance of the boards, by which the front of the shield was secured. These plates of metal (which were technically termed *staves*) were supported upon a cast-iron saddle piece, R, resting upon a swivel, S, which latter, being supported in front upon a kind of joint, U, and at the back upon a jack or strong screw, V, could be raised or lowered at pleasure. This mode of supporting the top staves allowed of their being brought into any position, or having any direction given to them. The tails of the staves were supported by a powerful jack-screw, W.

"The sides of the shield were secured, and the ground supported, by a number of similar staves, Z Z Z, fig. 135, attached to the frames by a sliding bar, passing through a block secured to the sides of the external frames, in such a way as to allow of their direction being altered as circumstances might require. The tails of the side staves overlapped the brickwork of the tunnel in the same manner as the top staves.

"The ground in front of the shield, as we have already mentioned, was supported by small boards of wood, *d d*, termed *poling boards;* each frame had its own set of *polings*, their length corresponding with the width of the frames. These boards were 3 inches in thickness, 6 inches in width, and at each end had small iron plates let in containing a recess, into

the head of a small e (termed the poling s), fitted; the other end se screws, resting in es formed for them, front rail of the cast-raming, A A, composing des of each box.

Fig. 137.



he frames of the shield not in actual contact, a of nearly 3 inches being ained between them, id the resistance which have arisen from the n of the frames if they been allowed to rub st each other; and in to preserve this space, floor-plates of every umbered frame was led at each end with of wrought-iron sectors of circles, *l l*, fig. 137 (or, as they termed, *quadrants*), the heads of which bore against the plates of the even-numbered frames, and the circum-ce of which worked in the recesses *m m*, formed in the plates of the odd-numbered frames for their reception. uadrants served only to prevent the frames approaching ose: to obviate their spreading, a powerful tie, formed o wrought-iron bolts, *t t*, fig. 135, was attached to the two nal frames.

ach frame was supported and maintained in a vertical on by two powerful screws, *f f*, fig. 136, termed the *ent* screws, one at the top and one at its lower extremity. heads of these screws rested against iron plates, *h h*, served to throw the pressure occasioned by the screw

over a larger surface of the brickwork. It was by means of these screws that the frames of the shield were advanced*.

"We now pass on to describe the mode in which the excavation was carried on and the shield advanced. We should first state, that every alternate frame of the shield stood three inches in front of the intermediate frames, which latter, when advanced, were moved forward six inches at a time, so as then to stand (in their turn) three inches in advance of the others. Thus, the odd-numbered and even-numbered frames alternately stood in advance of each other. We shall now suppose the odd-numbered frames to be behind, and proceed to detail the method of advancing one of them (No. III.), which will sufficiently explain the process adopted in the case of any one of the rest. Fig. 138 represents a sectional plan of a portion of the frames Nos. II., III., and IV., showing the relative positions of the front rails of those frames, together with their poling boards and the poling screws which supported them. This being the position of things, the first operation is, to remove the poling boards of the frame No. III., one at a time, commencing at the top of the box, and, having carefully excavated or cut away the ground to a depth of three inches, to replace the poling and its two screws; but instead of resting the latter upon their own frame, as they were before, they are now placed against the front rail of the two other frames on either side, as shown in fig. 139; the object of this arrangement being, that the intermediate frame, after all the poling screws have been so removed, shall be left entirely free to be advanced or moved forward without experiencing any resistance from the ground against its poling boards, the whole of which are then temporarily supported by its neighbouring frames. The frame itself is then moved forward the required

* "It should be mentioned that two shields were employed in the construction of the tunnel. That which we have just described was the second, and contained several improvements which experience had pointed out. They were, however, identical in principle, and in their general mode of action."

Fig. 138.

Fig. 139.

Fig. 140.

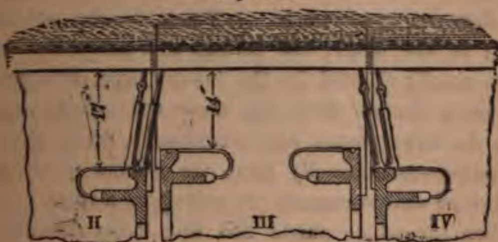


Fig. 141.

distance, or six inches, by means of the large abutment screws, *ff*, fig. 136; the mode of operation being, first, to relieve the legs of the frame from weight by means of the slings, in the manner already explained, then to move forward the two shoes, L L, fig. 135, bringing the legs into the sloping position shown in the fig. 136, after which the frame itself is screwed forward by turning the upper and lower abutment screws simultaneously, until the legs are brought again into a vertical position, and the frame assumes the situation shown in fig. 140, being then three inches in advance of its neighbours, Nos. II. and IV. The poling boards are now again removed, the ground once more excavated to a further depth of three inches, and the boards and poling screws again replaced, the latter being again restored to their own frame, so that they assume the position shown in fig. 141, the frames and polings of the odd-numbered divisions being now three inches in advance of the even-numbered frames, which latter, in their turn, will undergo a similar operation to that above explained.

"In fig. 136 the polings in the upper box are shown as having been worked forward, while in the middle and lower boxes they are represented as being in the act of being worked; in the latter, two polings are shown out at once; this was usually allowed in the lower boxes, the ground in which, being further from the river, was usually more solid than in the upper boxes, and occasionally, when the ground in the latter was unusually good, the miners in those boxes were allowed also to remove two polings at a time.

"When the whole shield had thus been advanced sufficiently to admit of a ring of brickwork being introduced, this was immediately proceeded with, the arches being turned upon a narrow centering or profile, *v*, fig. 136, and being inserted behind the abutment screws, *ff*, one at a time, care being taken that none of the poling screws were resting upon a frame whose abutment screws were not in proper bearing. As the shield advanced, a timber stage on wheels followed it, which afforded ready means of access for the miners and bricklayers to every part of the shield."

CHAPTER IV.

HYDRAULIC ENGINEERING.

BY

G. R. BURNELL, C.E.

HYDRAULIC ENGINEERING.

The subclassification of the branches of Civil Engineering, contained in the Introduction to this work, restricts the application of the above term to subjects connected with drainage, water supply, coast defences and harbours, and improvement of rivers. This classification will be adhered to in the following pages, and only such illustrations of the general scientific principles as are necessary to explain many of the phenomena encountered in the execution of such works, will be introduced.

The term hydrodynamics (from the Greek words ὕδωρ, *water*, and δύναμις, *force*) comprehends the whole science of watery fluids, under the several branches of *hydrostatics* (from ὕδωρ and ἵστημι, I place in equilibrium), which treat of their pressure when at rest, and *hydraulics* (from ὕδωρ and αὐλὴ, a pipe), which treat of their motion. *Pneumatics* (from πνεῦμα, vapour) treat of the pressure and motion of air and other light elastic fluids of a similar nature. The distinction between watery fluids and elastic fluids has been adopted, because, although in fact every description of fluid is compressible and elastic to a greater or less degree, nevertheless, the distinctive difference between the compressibilities of what are called the aqueous and the gaseous fluids, is so remarkable that the verbal distinction may be retained without inconvenience.

Fluids themselves may be defined as bodies whose molecules exist in a state of cohesion so slight, if even in some cases that state exist at all, that the particles are susceptible of being moved in every direction without experiencing any resistance. Different substances, known under the generic name

of fluids, have variable degrees of fluidity; and, indeed, it is generally believed at the present day, that the several states of solid, fluid, and gas (or elastic fluid), can be assumed by every substance in nature under the requisite conditions of temperature and pressure. The use of the respective terms must not, then, be considered as implying any necessary or absolute differences in the several substances, but as expressing rather the accidental qualities they possess, under ordinary circumstances. Water itself is a remarkable illustration of the faculty of any body to assume the three different states; in hydraulic engineering, however, our attention will be principally directed to its consideration under the fluid form.

Gases possess, in addition to the extreme mobility of their particles, the peculiar property of the existence of a species of repulsion between these particles, in consequence of which they dilate, or increase in volume, unless confined by pressure. Liquids, then, are further defined to be fluids having no tendency to increase in volume; and gases, to be fluids having such a tendency. Some gases, such as atmospheric air, may, for our purposes, be considered to be permanent gases; whilst others are so frequently condensed by the operation of ordinary natural causes, that it has been proposed still further to classify the gaseous fluids into the subdivisions of *vapours*, or those condensing easily into liquids, and *gases*, or those retaining permanently their peculiar condition.

1. Hydrostatics, or the Science of Water at Rest.

When water is perfectly pure and at its maximum density, its weight may be taken at 62 lbs. 5 oz. avoirdupois per cubic foot; and its specific gravity is usually considered to be represented by that quantity. Three causes, however, may contribute to modify this weight. The first, and the most important, is the temperature of the water; for it is well known that heat is able to dilate all substances, and thus to diminish their density or specific gravity. The second

modifying cause consists in the presence of the earthy or mineral salts which may exist in combination with the water. The third consists in the loss of weight which occurs when that property is ascertained, whilst the water is surrounded by atmospheric pressure: the influence of this modifying cause is susceptible of, perhaps, greater variation than the others, compared with the amount of influence it exercises.

The effect of heat upon the specific gravity of water has been ascertained by a series of careful experiments to be as represented in the annexed table, in which the specific gravity of water at 39°·20 Fahrenheit is taken as unity, for the purpose of making the table correspond with those adopted by scientific authorities abroad. Below 39·20 the density, instead of increasing, diminishes, slowly at first, but with greater rapidity as the point of congelation is approached; and the weight of ice itself does not exceed 0·930.

Temperature.	Weight.
39·20	1·00000
42·80	0·99995
46·40	0·99987
50·00	0·99972
53·60	0·99954
59·00	0·99914
68·00	0·99824
77·00	0·99709
86·00	0·99573
122·00	0·98758
212·00	0·95670

The effect of saline matters in combination may, under most circumstances, when fresh water is considered, be omitted; distilled water, usually taken as the type, not differing from river waters more than from $\frac{1}{10000}$ to $\frac{2}{10000}$. Observations made upon the waters of the Garonne indicated an average specific gravity of 1·000149; and similar observations upon those of the Seine gave, as nearly as possible, the same results. The specific gravity of sea-water is, however, much greater; it is 1·028, and a cubic foot weighs about 64 lbs. 2·5 oz.

The loss of weight arising from the displacement of the air by the water, may vary from $\frac{10}{10000}$ to $\frac{13}{10000}$ of the latter.

The effects of mechanical pressure upon the specific gravity of water are very inconsiderable, in a practical point of view. For many years, indeed, water was considered incompressible.

Later experiments have, however, demonstrated that it may be so compressed as really to diminish in volume, although to a very small extent. Under the pressure of one atmosphere the diminution is not above 0·000046 of the original volume; but as in ordinary calculations it is not necessary to reason upon depths of water so great as to make the effect of compression by the superincumbent fluid sensible, this consideration may be left out of question. And as the average specific gravity of water in our latitudes, at ordinary temperatures and under ordinary circumstances, only varies within the limits of 0·9984 and 0·999, the normal specific gravity being unity, it rarely happens that it is necessary to take any of these modifying causes into account.

The other physical properties of water, such as its porosity, elasticity, and cohesion, although of great interest to the philosopher, are of little importance to the engineer, whose operations are generally conducted upon too broad a scale to call for the examination of causes possessing a degree of influence which to him would be inappreciable.

In all investigations of the laws of equilibrium of water, it is admitted, in addition to the property already stated, that although under very great pressures it diminishes in volume, it may, for all practical purposes, be considered incompressible; that its molecules possess perfect freedom to move in any direction; and that it communicates equally throughout its mass the pressure exercised upon any point of its surface. It is also allowed, that any molecule of a definite liquid mass supports in every direction a pressure equal to the weight of a vertical column of similar molecules, starting from it and continuing to the surface of the liquid. From this last-named law some very remarkable consequences follow.

1. Every layer, so to speak, of a homogeneous liquid mass, supports an equal pressure on every point of its surface.

2. The sum of the pressures supported by a horizontal layer is equal to the weight of a liquid cylinder whose base

s the surface of the layer, and whose height is the distance from this layer to the surface of the fluid.

3. The pressure exercised upon any portion of a containing surface, whether horizontal, vertical, or inclined, is perpendicular to this surface; for the pressure must be destroyed by its resistance, and the surface of a body can only resist perpendicularly to its direction; and this pressure is equal to the weight of a liquid cylinder having for its base the portion of the surface under consideration, and for its height the distance to the surface of the liquid.

4. The pressures being equal upon all the points of the lower horizontal surface of a vase containing the fluid, the total pressure it supports is equal to that of the liquid cylinder whose base might be that surface, and whose height might be the distance between it and the upper surface of the fluid; so that this pressure would remain the same whatever be the form of the vase, provided that the area of the bottom and the height of the liquid did not vary.

The above laws furnish the means of calculating the resistances which vases containing fluids ought to offer, so as not to yield to the pressures exercised upon them. When a vase with a circular cylindrical section, or vertically conical, contains water, each horizontal ring is pressed on all its points by the column of water above it. Now, as in the case when all the points of a circle are equally pressed in an outward direction, the effect of this pressure to force out the circle at any point of its circumference is proportional to the intensity of the force acting upon each point, and to the radius of the circles, it follows, that the effort of a fluid to burst a circular vase, is proportional to the distance of the ring under consideration from the surface, and to the radius of the vase. If it were then desired to give the vase a thickness able to resist the pressure, or if it were only desired that the strength should exceed the effort in an equal proportion for the whole depth, it would follow that the thick-

ness should be increased in proportion to the height of the fluid above the point in question.

When the shape of the vase, instead of being cylindrical, augments in diameter towards the bottom, the forces tending to burst the vase augmenting, not only with the depth but also with the diameter, require that the increased thickness of the lower portions exceed that of the higher in a greater degree than if the vase were cylindrical. If, therefore, in a large vase a uniform thickness be given sufficient to resist the thrust at the bottom, it will be far in excess of what is required at the top.

The tangential traction exercised by a fluid upon the sides of a vase containing it, may be represented algebraically by the expression $\text{R}h$, in which $\text{R} =$ the radius, and $h =$ the pressure supported by the surface of the ring. The thickness necessary to resist this traction must, therefore, be such as to present a resistance greater than the effort $\text{R}h$ under any circumstances, whether arising from an accidental increase of pressure, or from a diminution of the resistance of the materials by oxidation or any other cause.

It is often necessary not only to ascertain the total value of the pressure exercised against any definite portion of the surface of a vessel, but also the point of application of the resultant of the pressures producing it; for this would be the point to which it would be necessary to oppose a force perpendicular to the surface, and equal to the supposed total value, in order to equilibrate it. This point is called the center of pressure.

Now it must be evident, that if the pressures exercised upon the different portions of the surface were coequal, the center of pressure would coincide with the center of gravity of the surface; but as the pressures vary with the distance from the surface of the fluid, the center of pressure is always below the center of gravity.

It is found that the center of pressure against a rect-

ngular surface whose upper side coincides with the surface of the water, is to be found upon the lines joining the middles of the horizontal bases, at a distance of two-thirds of its height from the top; or, calling x the center of pressure, the height of the rectangle measured on the line joining the middle points of its horizontal bases, $x = \frac{2}{3} l$. The center of pressure of a triangle, whose base is horizontal and upon the water line, is in the middle of the line joining the summit with the middle of the horizontal base, or $x = \frac{l}{2}$. The center of pressure of a triangle whose summit is at the water line, and whose base is horizontal and at the lower level, is on the line joining the summit to the middle of the base, and at three-fourths of the distance from that summit, or $x = \frac{3l}{4}$.

The principal application of these principles is to be found in calculating the supports required for large vessels containing liquids, which frequently come within the sphere of an engineer's professional duties.

Should the surface of the bottom of the containing vessel not be horizontal, as it has hitherto been supposed to be, the pressure exercised upon it will be ascertained by multiplying the area into the depth of the center of gravity from the surface of the fluid. It must be borne in mind, in all calculations of this description, that, whatever be the pressure upon the sides of any vessel, ascertained by the laws given above, the pressure upon the bottom is equal to the weight of the whole fluid acting upon it vertically. In close vases also, if any pressure be applied to the surface of the fluid, every portion of the containing sides and bottom would be affected by it. These laws are of the utmost importance in fixing the dimensions of constructions intended to hold or to resist the action of large bodies of water, such as reservoirs, cofferdams, sluices, &c.

It may be convenient to remember, that the pressure of

fresh water is always about 13 lbs. upon every square inch of horizontal surface, at the depth of 30 feet, whatever the form or position of the sides may be; and so in proportion for greater or less depths of water.

If still water be contained in vases communicating freely with one another by tubes or passages of considerable dimension, the equilibrium of pressure can only exist when it stands at the same level in both of them; and equally, if several vessels be employed, the condition of equilibrium will be that the same level exist in all of them; or, in other words, the pressure arising from the weight of a liquid being proportional to its depth, and being transmitted equally in every direction, the surface must always be at the same level in all vessels communicating freely with one another. It is upon the law of equilibrium of liquids in communicating vessels, that the principles of the connection of reservoirs are founded.

But the law in question only holds good when the communication is of a considerable sectional area, and the water is retained in the supposed vessels: when the passage is very small, the equilibrium becomes affected by a new power, known as the capillary action. This may be observed whenever a body or substance is partially immersed in water, for the latter either rises or falls round it, and, according as the body may be raised or depressed, the water assumes a concave or convex form. There are few substances in nature which do not possess the power of producing this phenomenon: polished steel is, however, one of the apparent exceptions; when plunged into water, that liquid retains its level at the point of contact with the surface of the steel.

The energy of capillary action depends very much upon the form, disposition, and distance apart of the sides of the tubes which excite it. In minute cylindrical tubes it is greater than in such as are prismatic, and in both it is greater than between parallel plates. The elevation or depression in cylindrical tubes is in the inverse ratio to the

diameter; in prismatic tubes, it is in the inverse ratio of the wet contour of a horizontal section; in the case of parallel plates, it is in the inverse ratio of their distance asunder. The surface of the fluid between the plates is perceptibly a demi-cylinder, with a semicircular base whose axis is horizontal; in a cylindrical tube the surface is that of a demi-sphere, whose diameter is equal to that of the tube.

Minute as the effects of capillary action may appear to a casual observer, they are of the greatest importance in many branches of practical science, and merit more attention than they usually receive from engineers. They have a very marked influence upon the durability of building materials, for it is worthy of observation, that the latter always begin to yield at the extremities of the zones of capillary action. In the cases of sea or river walls, the capillarity of the earth-work backing tends to augment its weight to a very serious extent; indeed, on account of this action, the earth in all such positions must always be considered to be a semi-fluid, denser than the earth itself in its dry or normal condition. Many failures have occurred from the neglect of this apparently self-evident law.

In order that a body may remain in equilibrium in the midst of a liquid, it is necessary—1, that its weight be equal to that of the fluid displaced; 2, that the center of gravity of the body and of the displaced fluid be upon the same vertical line; and 3, that the center of gravity of the body be as low as possible. The two first conditions evidently result from this, that the weight of the body and the pressure of the fluid are two parallel forces, which can only destroy one another when they are equal and directed in the same line; the stability resulting from the third condition follows from the principle that the center of gravity of a body always has a tendency to assume the lowest position.

When a body floats upon any liquid, the conditions of equilibrium are virtually the same as when it is entirely submerged; for the body tends to sink by its weight, and to

rise by the pressure which the fluid exercises upon the portion of its surface submerged, a pressure which is evidently equal to the weight of the fluid displaced, and applied to its center of gravity. It follows from this, that in order that a body may float upon the surface of a liquid, its weight must be less than that of an equal volume of the latter. Should the body be in a state of equilibrium, the weight of the liquid displaced is equal to the total weight of the body; and the center of gravity of the latter, as well as that of the liquid displaced, are in the same vertical line. The equilibrium will only be stable when the center of gravity of the body is lower than that of the water displaced.

The property by which bodies displace a quantity of water equal to their volume when their specific gravity exceeds that of the water itself, is usefully applied, if that specific gravity be known, to ascertain their precise weights. All that it is necessary to do in such cases is, to multiply the weight of the cubical contents of the volume of water displaced by the specific gravity of the material, and the result will be the weight of the body in question.

Specific gravity means the ratio of the weights of certain bulks of the substances considered to equal bulks of some other substance with which they are compared. Water being a substance but little exposed to variation, and with which most others can be readily compared, has been adopted as the standard. The specific gravity of gases is, however, ascertained by adopting the weight of dry atmospheric air as the standard. It follows that the specific gravity of a solid, or liquid, is obtained by dividing the weight of a portion of the substance by the weight of an equal bulk of water; and similarly, the specific gravity of a gas is obtained by dividing the weight of a given bulk of it by that of an equal volume of air. A table of specific gravities is attached; but it is particularly to be observed in practice, that the weights of equal volumes of two substances depend upon the weight of a definite unit of the term of comparison previously ascertained.

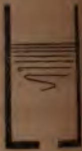
ance, if the unit of weight be a cubic inch of water, he substance to be compared with it will be ascery multiplying the number of cubic inches it may by the weight of a cubic inch of water, and by the number.

E OF SPECIFIC GRAVITY OF BODIES (HUTTON AND CARR).

re (Hutton) . .	23·400	Clay . . . (Hutton) . .	2·160
old ,, . .	18·888	Brick . . . . ,, . .	2·000
ilver ,, . .	10·535	Common earth . ,, . .	1·984
. . ,, . .	11·325	Sand . . . . ,, . .	1·520
. . ,, . .	13·600	Coal . . . . ,, . .	1·250
. . ,, . .	8·788	Box wood . . ,, . .	1·030
. . ,, . .	8·784	Sea-water . . ,, . .	1·030
. (Carr) . .	8·395	Common water . ,, . .	1·000
. . ,, . .	7·207	Ash . . . . . ,, . .	0·800
. . ,, . .	7·788	Maple . . . . ,, . .	0·755
. . ,, . .	7·816	Oak . . . . . ,, . .	0·925
. . ,, . .	7·291	Elm . . . . . ,, . .	0·600
. . ,, . .	7·196	Fir . . . . . ,, . .	0·550
. . ,, . .	3·329		
te . ,, . .	2·892	Sulphurous acid gas . . .	2·265
le . ,, . .	2·732	Carbonic acid gas	1·500
. . ,, . .	2·988	Nitrous gas.	1·194
. . ,, . .	2·864	Hepatic gas	1·106
. . ,, . .	2·741	Oxygen gas	1·103
. . ,, . .	2·654	Nitrogen gas	0·985
. . ,, . .	2·765	Ammoniacal gas	0·600
. (Hutton) . .	2·570	Hydrogen	0·084
tones ,, . .	2·520	Atmospheric air	1·000

ULICS, OR THE SCIENCE OF FLUIDS IN MOVEMENT.

ave seen that when a fluid is contained in a vase of , it exercises, in consequence of its gravity, pressures ery portion of its surface perpendicular thereto. If, e vase be perforated, the liquid will escape with a elocity; and at the same time certain movements will ce in it whilst in the interior of the vase, which we eed to notice.



When a small hole is made in the bottom of a vase the molecules move vertically to within a short distance of the orifice, supposing that the top surface be exposed to the direct influence of the atmosphere, but the other molecules flow towards the orifice from every direction. If the orifice be on the side of the vase, the molecules, both above and below, move towards it; so that in every case their movement is towards the orifice from every direction, and as the same quantity of liquid must pass through the same space in the same time, if the pressure be uniform, the mean velocity of each such quantity must be in the inverse ratio of the surface it occupies in the vase.

The upper surface of the liquid in the vase is not always terminated by a horizontal plane. When the jet escapes vertically by an orifice in the bottom, and the level has nearly fallen to that of the orifice, the liquid withdraws from the line of its axis and assumes the shape of a funnel, whose apex is in the center of the orifice. If the liquid had a rotary movement in the vase, or if the shape of the latter were of that description, the funnel formed by the upper surface of the fluid would be developed at an earlier period. If the orifice were lateral, the funnel would not be formed, but the surface of the liquid would be depressed immediately above the orifice, as in the accompanying figures.

These movements depend upon the form of the vases, the height of the liquid, and the position and dimension of the orifice. Hitherto it has not been found possible to bring them under any general laws.

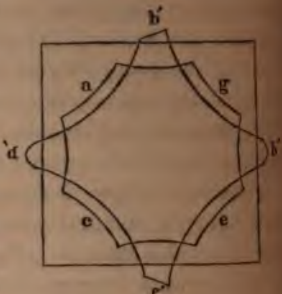
The liquid vein escaping from an orifice takes the form of a prism whose base would be the orifice itself, but which diminishes gradually until it reaches a distance from the latter equal to about half its diameter, where its thickness is not more than 0·6 or 0·7 of the orifice. This diminution is known by the designation of *the contraction of the fluid vein;* and it takes place in whatever direction the water may flow. When, however, the jet takes place vertically downwards, the prism contracts for a greater distance, because the velocity of each horizontal layer increases in proportion to the space fallen through, and therefore the distance between any two layers must also increase. For the same reason, when the jet takes an upward direction the prism enlarges after the contracted vein, because the velocity diminishes. In all cases, beyond a certain limit, the resistance of the air divides the jet into drops of greater or less volume. In vacuo, the jet, if not vertical, would describe a parabolic curve in falling, like solid bodies.

The cause of the contraction of the fluid vein does not appear to arise from any contraction of the fluid itself, but it lies in the fact that the molecules leave the orifice with different parallel velocities. Those which pass through the center of the orifice have an initial velocity greater than the others, and necessarily the column must diminish; in a short time, however, the velocity becomes equalized throughout the column, and it would remain constant if the pressure and the resistance of the air did not interfere with it. The inequality in the velocity of the molecules is caused by the various inclinations under which they approach the orifice, and by the friction against the sides of the latter.

When the jet is vertical and downwards, and the liquid has a rotary movement, a species of funnel is formed in the interior of the vase, and the liquid leaving it assumes a similar form, but its apex is in precisely the opposite direction to that of the funnel in the interior. If the sides of the orifice be

not perfectly even, and the liquid in the interior be impressed with a rotary movement, the liquid in escaping often takes the form of a spiral column.

When the orifice is polygonal, or of any other than a circular form, the outline of the fluid vein is more complicated, but the results are not affected. The different parts of the orifice not being symmetrical, the vein does not retain the form which it had on leaving the orifice, but it changes continually as it increases in distance. Immediately after leaving the orifice the faces corresponding to the rectilinear sides become hollow, and the concavity increases; the edges corresponding to the angles are splayed off, and finally they disappear entirely. Thus MM. Poncelet and Lesbros ascertained that the form of a vein leaving an orifice perfectly square, measuring 8 inches on each side, at a distance of 6 inches presented the section $a\ c\ e\ g$; and at 1 foot, the section became $b'\ d'\ f'\ h'$. This last was its smallest section, and its area was 0·562 to 1 of the orifice, whilst the effective quantity discharged was 0·605 to 1 of that indicated by theory. The head of water above the orifice was 5 feet 7 inches.



In this case the vein seems to have made the eighth of a revolution upon its axis; and the researches of Bidone show that many other interesting phenomena occur in the course of a jet. The reader is referred to his very interesting work, "Expériences sur la Forme et la Direction des Veines et Courants d'Eau lancés par diverses Ouvertures," for more complete information on the subject. It may suffice to state, that if the jet be of any length, a series of contractions and expansions takes place in it, accompanied by changes in its transverse section when the form of the orifice is pentagonal.

The velocity with which a fluid leaves an orifice is, at the mmencement, imperceptible; it increases for a certain peod, after which it remains constant, if the level of the fluid ntinue the same in the vase, or it decreases if the level be wered. Whatever be the form of the opening, or whatever its size compared with the transverse section of the vase, long as the water in the latter remains still, the constant locity with which the fluid will escape will follow the me law.

When the orifice is made in a thin plate, or when the ickness of the side of the vase does not exceed the smallest imension of the orifice, and is, at a maximum, only from 2 to $\frac{3}{4}$ inches, the rate of flow, when no initial velocity exists, is curately expressed by Toricelli—

$$V = \sqrt{2gh}, \text{ from which } h = \frac{V^2}{2g}.$$

V = the theoretical velocity; the real velocity is found be from V − 0·1 V to V − 0·2 V; the diminution in the elocity being attributable to the friction of the water against he sides of the orifice, and to the resistance of the air.

In the above formula h = the height of the liquid in the ase above the center of gravity of the orifice.

g = the acceleration of motion due to gravity in a second; t is in London considered to be $32\frac{1}{6}$ feet.

The velocity in this case is that which a heavy body would cquire in falling in vacuo through h; and as the velocity is roportional to the square root of the height of the liquid bove the center of gravity of the orifice, if the height be uadrupled the velocity will only be doubled.

When the liquid flows through an orifice whose length is times its smallest transverse dimension at a minimum, or hen an ajutage is employed whose length is equal to two or hree times the smallest dimension of the orifice, the formulæ ecome $V' = 0·82\ V = 0·82\ \sqrt{2gh}$; V′ being the real velocity ith which the water flows, and the other notation as before.

D 2

The velocity is modified if the two faces of the orifice be under water, and it becomes $V = \sqrt{2g(h - h')}$, in which h' = the height of water in the second recipient, and $(h - h')$ = the difference of levels between the water in the two vessels, retaining the preceding values of V, g, and h. If the discharging vessel be subject to any pressure, the formula becomes $V = \sqrt{2g(h + h')}$, in which h' = the pressure exercised, expressed in the height of a column of the liquid.

If we leave out of account the diminution of the velocity and the contraction of the fluid vein near the orifice, the theoretical discharge would be $Q = SV$; in which Q = the quantity discharged per second, S = the sectional area of the orifice, and $V = \sqrt{2gh}$. But the quantity which really flows from any orifice differs considerably from that indicated by theory, and it is usually expressed by the formula $Q = KSV$, in which the new term K = the coefficient of discharge, or the ratio of the real to the effective quantity flowing from the orifice. The value of this coefficient depends upon the pressure upon the orifice, its form, and its position in the sides of the vase.

The greatest contraction takes place when the orifice is removed from the bottom and the sides of the vase by a distance at least equal to 1 or 1½ times its smallest dimension, under which circumstances the contraction takes places all round. But, if the sides of the opening be in the prolongation of the sides of the vase, the coefficient of contraction requires to be multiplied by 1·035, in the case when the prolongation exists on one side; by 1·072 when it exists on two sides; and by 1·125 when it exists on three sides. MM. Poncelet and Lesbros have determined the values of the coefficient of discharge for rectangular orifices with the greatest contraction, and they are presented in the table No. 1 of Appendix, in which the dimensions are given in English feet and inches. They are equally applicable for other forms of orifice, without any inward projection, provided that the

smallest dimension be that of the height of the table; and they are equally applicable when the discharge takes place in the open air or under water. It is important, however, to observe that, if all other conditions remain the same, the contraction diminishes in proportion to the thickness of the orifice, for when the latter is considerable it acts to a certain extent as an ajutage; and that when the sides of the vessel are convex outwards the discharge is increased, whilst, on the contrary, it is diminished if they be convex inwards.

In the sluices of lock gates, the sills of which are generally close upon the floor of the lock chambers, the coefficient of discharge is always 0·625, whether the sluice work in water or not. Formerly it was usual to adopt a coefficient of 0·55 when two sluices were used, but more recent experiments appear to show that the real coefficient should be, as in the last case, 0·625. With inclined sluices, such as are used in Poncelet's wheels, the lower and side faces of which are in the prolongation of the reservoir, the coefficient is 0·74 if the upper face have an inclination of 1 to 2; and 0·80 if the inclination be 1 to 1; the sectional area being obtained from the vertical height, not from that measured perpendicularly to the opening.

The effective discharge of weirs, or overflows, is stated by Poncelet to be represented by the formula

$$Q = K L H \sqrt{2 g H}.$$

Q = the effective quantity falling over.

K = the coefficient of discharge; which generally = 0·405, according to that authority.

L = the width of the overflow.

H = the height of the water above the sill of the overflow: this height is to be ascertained at a point where the level of the water is not affected, or usually at about from 4 to 8 feet above the overflow.

In table 2 are given the various coefficients for different values of H observed by MM. Poncelet and Lesbros. And it

further appears from their investigations, that the usual co-efficient 0·405 becomes 0·42 when the overflow is of the same width as the leading channel, and when the depth of the latter corresponds nearly with H. If we call the thickness of the sheet of water falling over, measured upon the inner edge of the overflow, h, it will be found that $\text{H} = 1{\cdot}178\, h$, when the overflow is $\frac{4}{5}$ths of the width of the reservoir; and that $\text{H} = 1{\cdot}25\, h$, when the two widths are equal.

When cylindrical tubes are added to an orifice in any vase or reservoir, the discharge through the former is greater than that through the latter, supposing the conditions of the head and of the sectional area to remain the same. This effect will not, however, be produced unless the water fill the orifice of discharge, which will take place when the length of the tube is three or four times its diameter; but, on the contrary, will not take place when the length of the tube is smaller than that of the contracted vein. If the ajutage be cylindrical, and the water fill it entirely, the increase in the discharge, when the length of the ajutage does not exceed four times its diameter, is in the proportion of 1·33 to 1·00.

The effective discharge may be still further increased by making the ajutage cylindrical, and of the form represented by the accompanying figure, provided the liquid fill it entirely. This ajutage is composed of two portions of cones upon the same horizontal axis; the first has the form of the contracted vein, the length of the second is three times that of the first, and the opening, $m\ n$, of the first, is $\frac{7}{8}$ths of $p\ q$ of the second. The effective discharge through an ajutage of this description is in the proportion of 3 to 2 of that which would take place through an orifice in a thin plate.

In the case of the discharge of water through long pipes, if the latter have a general fall, the velocity of flow is increased by the effect of gravitation; and as the liquid column

prevented from changing its form by the adherence to the des of the pipes, and by the resistance of the air, the lower aments of the liquid transmit a portion of their velocity to e upper ones, and establish a general uniform velocity, hich increases in proportion to the length of the pipe up to certain point, beyond which the friction stops its increase. horizontal pipes this friction repeated upon a great length nds continually to diminish the velocity; so that if the ngth be considerable in comparison with the initial velocity, e liquid will hardly flow at all.

Eytelwein states that, in consequence of the existence of is friction, the head of water producing motion in a pipe ay be divided into two parts, one of which serves to enerate the velocity, and the other to overcome the friction. his portion must, therefore, be directly as the length of the ipe, and the circumference of the section (or as the diameter f the pipe), and inversely as the contents of the section, or s the square of the diameter. This subject will be found reated more in detail in the subsequent chapter of this work evoted to the consideration of the water supply of towns, on ccount of its more intimate connection with that branch of ydraulic engineering.

It appears from numerous experiments, that the rate of low in pipes is not sensibly modified by the nature of the ubstance of which they are formed, and that it depends alone upon the length and diameter. The resistance increases in proportion to the square of the velocity, the length of the pipe, and in the inverse ratio of the diameter. Any curves or deviations from the straight direction, whether in a vertical or horizontal direction, diminish the velocity considerably. If hey cause a severe shock, it is even possible that they may o effectually disengage the air in suspension in the water as o entirely interrupt the flow.

In capillary tubes, as might naturally be expected, the elocity is more affected than in those whose diameter is con-

siderable, because the friction only affects those portions of the liquid which touch the sides of the tubes, and it must, therefore, be the greatest when these are in immediate proximity to the axis.

Bernouilli observed that when liquids flowed in pipes, the pressure they exercised against the sides of the latter was always less than the pressure they would exercise if they were in a state of rest. The effective pressure is stated by him to be equal to the height of the liquid at the point observed, diminished by that of the liquid able to produce the velocity actually existing at that point. From this it would follow that the pressure will always be in the inverse ratio of the velocity, and that it would be annihilated if the latter were really that due to the head over the point of observation. This law has been verified by a sufficient number of experiments to be received as correct.

In channels, the fact of the upper sides being open modifies to a serious extent the conditions of the flow of water; and it is found that, whatever be its section, if a uniform velocity be once established, it will deliver the same quantity of water at one end which it receives at the other; consequently, in any transverse section of the channel the same quantity of water must pass in the same period of time. It follows from this, that the velocity of the current must increase in proportion to the diminution of the channel; and, on the other hand, it must diminish in proportion to the increase of the latter. As the rate of flow is produced by the action of gravitation, it must increase with the inclination; and in order to obtain an equable discharge, the several conditions of the dimensions and inclination must co-ordinate. In a channel with a uniform inclination and section, however, the rate of flow is uniform, because the friction of the sides destroys the increase of velocity which would otherwise be produced by gravitation. From this friction upon the sides it also follows that the velocity is not equal for all the molecules; those which are

nediately in contact with them are retarded in their flow, . in their turn they retard the molecules immediately around m. Of course the maximum velocity exists at the surface the current.

'rom the experiments of Dubuat it appears that the mean ocity of any stream in an open channel, represented by v, equal to a coefficient of the maximum velocity varying ween 0·76 and 0·891; the maximum velocity being repreted by V. It is usual in practice, therefore, for surface ocities varying between 8 inches to 5 feet, to consider that $= \frac{4}{5}V$, or $V = 1{\cdot}25v$. But in large rivers these formulæ e velocities in excess of those actually found to exist; for as been ascertained by actual observation, that in the Seine $= 0{\cdot}62V$; and M. de Rancourt found that in the Neva $= 0{\cdot}75V$.

The German engineers who have examined this subject e found that the mean velocity of all the fluid veins t by the same vertical line bore a proportion to the ocity at the highest point on that line, varying from 8 to 0·92. From the experiments made by M. Defonne upon the Rhine, this ratio would appear to be 0·88 in t river.

Dubuat concluded, from his observations, that the velocity the bottom of a channel, calling it U, was $U = 2v - V$, eping the same significations of v and V; and from this, if $= 1{\cdot}25v$, $U = 0{\cdot}75v$, or $v = 1{\cdot}3\dot{3}U$. In the formation of y watercourse, then, U must be taken of such a velocity as t to allow the materials of the bed to be carried away; and other dimensions will be ascertained from the following mulæ for channels of a uniform inclination and constant tion.

In this case, calling Q the discharge, S the sectional area, l v the mean velocity, we have $Q = Sv$; from which also have $v = \frac{Q}{S}$. The inclination will be ascertained, calling

it I, by the formula $I = \frac{P}{S}(av + bv^2)$ according to De Prony. In this, $P =$ the wet contour, S the sectional area, and a and b numerical coefficients which he makes respectively 0·0000444 and 0·000309. Eytelwein was induced to change these coefficients from some other observations, and to make $a =$ 0·000024, and $b = 0·000365$. But it would appear that Eytelwein's values of a and b are only correct for large rivers; whilst for channels whose sectional area would be about 10 yards superficial, De Prony's are more correct.

If we call the quotient of the transverse section of the watercourse S, by the wet contour P, the mean radius, and represent it by R, we have $R = \frac{S}{P}$; and the formula of De Prony gives us*, replacing a and b, by his values,—

$$RI = 0·0000444\,v + 0·000309\,v^2,$$

from which we obtain—

$$v = \sqrt{0·005163 + 3233·428\,RI} - 0·07185, \text{ or nearly;}$$

$$v = 56·86\,\sqrt{RI} - 0·072.$$

From these formulæ it will be easy to ascertain the value of v, if I and R be known, or to ascertain the inclination, I, necessary to obtain a velocity such that $v = \frac{Q}{S}$. The value of R depends upon that of the section S, and the form of this section, which, generally speaking, is regulated by local considerations. If the channel be in wood or in masonry, it is preferable to make the sides vertical, and the width equal to

* De Prony's values are given in metres; and in Playfair's "Outlines of Natural Philosophy" they will be found translated into English; but if the yard, divided decimally, be used as the unity instead of the metre, no very serious error can arise from the application of the values given by the first-named author. It may perhaps not be out of place to express regret that the very perfect and beautiful system of weights and measures of France are not universally adopted, instead of the numerous absurd and arbitrary measures we find to prevail in other countries.

twice the depth of the water, so as to render the wet contour, and consequently the surface producing friction, as small as possible. For canals in earthwork the slopes vary, and the width ranges from four to six times the depth of the water.

De Prony's formula $v = 56{\cdot}85 \sqrt{\text{R I}} - 0{\cdot}72$ will serve not only to ascertain the discharge of a channel of a uniform inclination and constant section, but also to gauge any stream, provided a length of about 500 yards can be found upon it where those conditions may be fulfilled. A cross section will give the area and the wet contour of the stream, and dividing the former by the latter the mean radius, R, will be found; a longitudinal section will give the total inclination of the regular portion of the stream, and this inclination, divided by the developed length of the axis, will give the partial inclination in each unity of length. If the section of the stream should not be constant, which is frequently the case in natural channels, a certain number of cross sections must be taken in the portion where the stream is most regular, from which an average must be obtained. The wet contour, and the mean radius, R, are also to be found by taking the averages derived from the series of cross sections. The inclination is then to be ascertained from the mean velocity, v, and the discharge by the ordinary formulæ. Should it happen, however, that the stream is divided into two portions, one of which is very deep, and comparatively speaking narrow, whilst the other is shallow and broad, it would be preferable to consider the stream as divided into two separate branches, and to calculate the discharge of each of them.

It is possible, also, to ascertain the volume of a river by determining the maximum velocity at the surface, observing all the precautions necessary to insure a correct mean result. The transverse section must also be ascertained from the average of a sufficient number of profiles, and the discharge will be obtained by multiplying the sectional area by the mean velocity, which we have seen to be $0{\cdot}8$ V. It is essential

that the floats be thrown into the stream a little above the points of observation, in order that they may have the velocity of the latter during their passage.

The preceding observations apply when the volume of water passing an orifice, or through any given portion of the channel of a stream, is such as to maintain a constant head. If, however, the discharge be greater than the supply, the level of the water above will lower, and the head necessarily be diminished. The value of H in such cases will have to be modified, so as to express the effective average head influencing the discharge during the entire operation. It has also been assumed that the discharge takes place in the open air, and without any resistance on the under side; but in the case of one reservoir pouring its waters into another, not only does H require to be modified, but a new term requires to be introduced to express the variable resistance of the water on the under side as it rises above the orifice of communication.

Morin gives a rule to ascertain the discharge when a variable head exists over the center of an orifice, which may be stated as follows. A vertical rule is placed in the reservoir, upon which are to be measured the levels corresponding to equal intervals of time; for ordinary purposes five observations will suffice. Then, calling L the width of the orifice, E its height, m the coefficient of discharge, the arithmetical mean between the values corresponding with the greatest and least heads observed, h_1, h_2, h_3, h_4, h_5; the levels at the different intervals of time t; the quantity discharged during the total period, or $4t$, will be

$$Q = 1{\cdot}476\, m\, LEt\, [\sqrt{h_1} + \sqrt{h_5} + 4\,(\sqrt{h_2} + \sqrt{h_4}) + 2\sqrt{h_3}].$$

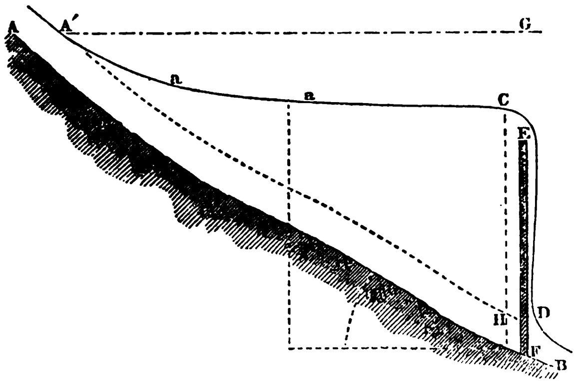
The formula becomes, when the flow over a weir is considered,

$$Q = 0{\cdot}598\, Lt\, [h_1\sqrt{h_1} + h_5\sqrt{h_5} + 4(h_2\sqrt{h_2} + h_4\sqrt{h_4}) + 2h_3\sqrt{h_3}];$$

and when the orifice may be covered with water on the under side, the heads h_1, h_2, &c., must be replaced by the differences of the heads on the upper and under side at the same periods of observation; that is to say, h_1 becomes $H_1 - h_1$, and h_2 be-

omes $H_2 - h_2$, &c., calling H the head on the upper, and h that on the under side of the orifice.

In all rivers there will be found to exist a greater or less extent of comparatively still water in immediate proximity to the bank, which also appears to form a series of eddies, arising probably from the impulsion of the current. The principal direction of these eddies appears to be opposite to that of the current; and when any obstacle is offered to the onward flow of the latter, the water becomes heaped up, as it were; and in this case also a kind of return takes place, from a change of direction in the flow of the liquid. A dyke or embankment in a river will produce this effect; or, in fact, any construction which diminishes the passage, such as groins, bridges, &c. There is no word in the English language which expresses this effect, and it may therefore be as well to adopt the French phrase " remous " to express the increase of height and the change of direction produced in a current by the intervention of any obstacle to its flow.



In the case of a dam across a stream, the bed of which is represented to an exaggerated scale by the line A B, and the dam by E F, the water will rise on the upper side to fall subsequently over the edge of the dam. The fluid mass represented by A′ a a C D will constitute the remous.

The greatest depth of the remous, excepting in so much as it is modified by the conditions mentioned in the next sentence, will exist immediately over the edge of the dam E F, and will be derived from the height of the latter, diminished by the original depth of the water, and increased by the height of water standing on the edge. This last quantity has been ascertained by M. Castel to be obtained by the formula $x = 0{\cdot}64 \sqrt[3]{\left(\frac{Q}{L}\right)^2}$, in which $Q =$ the volume of the current, and L the width of the dam. Should the water, however, instead of falling over the edge, be withdrawn by a series of sluices at the lower part of the dam, the greatest depth will be equal to the distance between the center of the openings and the bed, added to the distance between the center and the top level, which will be found by making $x = 0{\cdot}1805 \frac{Q^2}{A^2}$, a being the sectional area of the openings.

But the greatest height of the water above the horizontal line does not take place immediately upon the dam; it occurs at a small distance above it. The same thing happens in this instance as in all others where water flows over a weir, viz., that shortly before it arrives at the edge it slopes towards the latter, and in large remous this sloping will begin at a considerable distance above. The height of the remous at any distance from the edge of the dam will result from the nature of the curve assumed by the surface of the water on the upper side. This is unquestionably a hyperbola, whose summit is at A′, whose axis is AC, and which is nearly tangent to a line passing through A at such a distance that $EG = \frac{2\,EH}{l}$, in which expression $l =$ the length of the dam.

During the inquiries conducted by the Italian engineers for the purpose of discovering a simple self-acting gauge for the irrigation of that country, a very interesting fact was noticed which indicated that the ordinary laws of hydrostatics were, to some extent, modified when the water was set in motion.

It was ascertained that in a vase, constantly supplied, but divided into two portions by a diaphragm susceptible of being moved vertically, and with a discharging orifice on one side, a constant difference of level existed so long as the water flowed; and that this difference of level was greater in proportion as the opening of the diaphragm was less, compared to that of the orifice. And if, by any change in the direction of the supply, or of the flow, the level were made to alter on either side, the corresponding variations upon the two sides of the diaphragm continued to be always proportional with the respective differences of level first established. This law is not affected by the introduction of two or more diaphragms; for a similar variation of level takes place between each of them, and is maintained so long as the water continues to flow. Of course, if the discharge cease, the hydrostatic pressure will cause the water to assume the same level in all the communicating compartments.

If we suppose a fluid to be contained in a reversed syphon, each of whose branches is of the same diameter, it will be found to stand at the same level in both of them; and if by any means the column be now raised in one, and then left free, it will descend below the original level in consequence of the velocity acquired; it will remount above that line, and continue to oscillate about it for a certain time. These oscillations are found to be isochronous, and if the branches of the syphon be vertical, their duration will be equal to that of a pendulum whose length is equal to half the total height of the liquid column.

When any point on the surface of a pool of still water is disturbed, a series of small waves is formed, which extend with great rapidity. These waves are found to be of two sorts: the first are formed at the same moment in great numbers, and are propagated in every direction with a uniformly-increasing velocity, like that of the fall of heavy bodies, and the distance of any two summits increases in the direct ratio of the square of the time; whilst the heights decrease in the

inverse ratio of the same square when the liquid is contained in a channel of a constant width, or according to the fourth power of the time when the liquid is entirely free. The second series also rise in infinite numbers and at the same time; but they are propagated uniformly with a velocity proportional to the square root of the diameter of the shock: the heights of the summits decrease in the inverse ratio of the square root of the time, or of the first power thereof, according to whether the liquid be contained in a channel, or entirely free. The second description of waves are more appreciable than the first, especially near the point of origin; and any wave which is formed on the surface of a liquid mass is propagated to a considerable depth in the interior.

When the waves come in contact with a fixed body, they are interrupted in a portion of their course, and that portion of the wave which strikes the resisting body is reflected back upon itself, and propagated in an opposite direction; they are, however, re-formed beyond the obstacle, if it be isolated, and extend beyond it as though they had not been interrupted. When several centers of disturbance are formed in a piece of still water, the series of waves may be observed to cross one another without any decided interference. These observations, however, are only applicable to small bodies of water; in the subsequent portion of this treatise attention will be more particularly called to the laws affecting the interference of waves at sea.

Bodies moving in fluids meet with two species of resistance; the one arising from the movement communicated to the portions of the liquid successively displaced, and the second arising from the power necessary to separate the parts of the liquid between which the bodies move. Up to a certain velocity the resistance of fluids from the first cause is found to be equal to their density; to the square of the sectional area of the body moving in them, modified to a considerable extent by their forms; and to the square of the velocity. The resistance arising from the cohesion of the fluid was found by Cou-

omb to be proportional to the velocity: to be independent of he nature of the surface of the body: and the pressure to which the fluid is exposed to be equally without influence on he value of the resistance. Thus any body moving in a iquid meets with a resistance composed of two terms; the ne due to the inertia of the liquid increasing as the square f the velocity, the other due to the cohesion increasing imply with the velocity.

The researches of Mr. Scott Russell upon the movement of canal boats at high velocities show, however, that beyond a elocity of about 13 feet per second, some new, and hitherto ut imperfectly understood laws come into operation. In the words of the Report of the British Association for the Advancement of Science, our present knowledge of the subject may be thus expressed:—"The resistance of a fluid to the motion of a floating body will rapidly increase as the velocity of the body rises towards the velocity of the wave of displacement caused by the said motion, and it will be greatest when he two velocities approach equality.

"When the velocity of the body is rendered greater than hat due to the wave, the motion of the body is greatly facilitated. It remains poised on the summit of the wave in a position which may be one of stable equilibrium; and this effect is such, that at a velocity of 9 miles per hour the resistance is less than at a velocity of 6 miles per hour, behind the wave. The velocity of the wave is independent of the width of the fluid, and varies with the square root of its depth.

"It is established, that in every navigable stream there is a velocity at which it will be more easy to ascend against the current, than to descend with the current. Thus, if the current flow at the rate of 1 mile per hour in a stream 4 feet deep, it will be easier to ascend with a velocity of 8 miles per hour on the wave than to descend with the same velocity behind the wave. The velocity of the wave of displacement itself is about 8 miles per hour."

Projectiles, when they strike the surface of a liquid, meet

with a resistance which diminishes their velocity and changes their direction. The intensity and direction of this resistance depend upon the form of the body, and its velocity. At all times, however, it tends to raise the direction of movement and to carry it towards the surface of the liquid; should the original direction of the projectile be but slightly inclined to the horizontal line, the shock will even cause the projectile to rebound as if the surface had been solid. It is for this reason that stones thrown from a small angle, or bullets fired from batteries near the water line, rebound a great number of times before their velocity is sufficiently retarded to allow of their sinking permanently below the surface.

When a fluid is in motion a certain portion of the force by which it is animated may be employed to drive a machine. Of course the motion thus utilized must be owing to the gravity of the water itself, for if it were necessary to give rise to it by the application of some other force, it would evidently be preferable to apply that force directly to the machine. In the useful arts, then, water is only applied when it flows in an inclined channel, or when it falls suddenly from a height. But it must be observed that, whatever be the nature of the machinery employed to transmit the power of the water, a certain portion must always be lost: 1st, because the whole velocity cannot be destroyed, or the water after producing its effect could not flow away; and 2nd, because the intermediate machine transmitting the power of the water has a motion and a velocity proportionate to the latter, which consequently can only act by the excess of its velocity over that of the machine.

Water may act as a motive power in several different ways: either by percussion, by pressure, or by reaction. It acts by percussion when it strikes the portions of any machine placed in its course, and, after communicating its movement to the machine, flows away immediately after the shock. Float-wheels placed in a current are illustrations of this action. Water acts by simple pressure when, having no initial velo-

city, or one which is very small, and only equal to that of the body on which it acts, it moves this merely by its weight; as in the case of bucket wheels when the velocity of the periphery of the wheel is equal to that of the stream. Water acts both by percussion and pressure when it falls upon a bucket wheel with a velocity greater than that of the wheel itself. And lastly, water produces its effect by reaction in turbines, or the class of mills called reaction mills for this very reason. In the case of the hydraulic press, the law by which a liquid inclosed in a vessel on all sides is able to transmit to every portion of its bounding surface a pressure exercised upon any one point thereof, is called into action. But as the details of these various machines form part of the science of practical mechanical engineering, rather than of civil engineering itself, the reader is referred to the other Numbers of this Series, in which that branch is more particularly considered.

Pneumatics.

Correctly speaking, the term Pneumatics ought to be confined to the science of the phenomena connected with the atmosphere; but by extension it has been made to include all the gaseous fluids. Our observations will, however, be confined as much as possible to the narrower acceptation of the word; and the gaseous fluids, other than the atmosphere, will only be treated of as connected with the latter.

As was already observed in the Section on Hydrostatics, gaseous fluids differ from aqueous fluids in this—that the former are highly elastic, whilst the latter are only very partially so. Of the gases themselves, again, there are some which are permanently elastic, and others which by means of compression can be converted into liquids. *Air* is an illustration of the former, steam of the latter class; but Faraday's beautiful researches lead to the belief that this distinction only exists in consequence of the imperfection of our

means of operating upon them, and that all gases are susceptible of being condensed, under favourable conditions. In ordinary language it is, however, convenient to retain the distinction between the condensible and the incondensible gases, giving the former the specific name of *permanent gases*, and the latter that of *vapours*.

The properties common to all gases may be stated as follows:—1stly, that their elements have weight; 2ndly, that they tend constantly to dilate, in consequence of the repulsive force of their latent caloric exceeding the molecular attraction, and that they only retain the same volume from the resistance of some containing body; 3rdly, that they are compressible by reason of the space around their molecules; 4thly, that they are elastic, inasmuch as, when their molecules are brought into closer connection with one another, the repulsive force of heat increases more rapidly than the attraction; 5thly, that their molecules are perfectly free to move on one another; and 6thly, that by reason of their elasticity a force exercised on one point must be transmitted throughout, and in every direction. All these properties have been demonstrated to be possessed by atmospheric air.

Since the atmosphere possesses weight, compressibility, elasticity, and the power of communicating pressure in every direction, it follows that any portion of it must be pressed by the weight of that immediately above it, and must also transmit the effect of this weight to the portions below it; consequently the density of the atmosphere and its elasticity must decrease as the distance from the earth increases. A body thus placed in the air must therefore be exposed to a pressure upon every part of its surface which diminishes with its elevation.

The atmosphere revolves with the earth, and at the same velocity with it; for otherwise the air at rest would create a resistance to motion equal to the shock which would ensue if the earth stood still. A current of air, in fact, would be felt

velocity would be equal to that of the earth's rotation axis, or about 1518 feet per second; whilst the most hurricanes, such as are able to tear up trees and over- buildings, do not travel at a rate exceeding 147 feet per l. As the atmosphere moves with the earth, all the ules composing it are affected by three forces—gravity, ity, and the centrifugal force. Under these circum- es, as the weight and the elastic force of the molecules atmosphere diminish in proportion to its distance from xis of rotation, whilst, on the contrary, the centrifugal increases, there must necessarily exist upon any vertical ng through the center of the globe a point where these forces are in equilibrium, and the atmosphere must be ed. It has been ascertained that the distance at which atmosphere becomes rarefied to such a degree as to be times lighter than it is at the ordinary level of the earth rarefaction equal to that obtained by the best pneumatic ines—is about 58,000 yards above that level. This is more than $\frac{10}{1225}$ of the radius of the earth; so that it be considered that the height of the atmosphere is about l to $\frac{1}{100}$ of the radius.

a tube be made air-tight and filled with any liquid so as tually to exclude the air, and then immersed in a vessel l by some other liquid whose surface is exposed to the sure of the atmosphere, it will be found that a column will istained in the tube, the height of which will depend upon pecific gravity of the liquids, and be in the inverse ratio of r density. The force which sustains these columns is the sure of the atmosphere acting directly upon the exposed ice of the vessel, and pressing it in a downward direc- whilst the liquid in the tube is exposed to no such n; and the effect will be the same, whatever be the sec- and dimensions of the tube, provided they be not so small allow capillary attraction to modify it. Moreover, this ure of the atmosphere may be demonstrated to act on side, for if the tubes be made to assume any direc-

tion, the liquid in them will rise to the same height above the level of that contained in the vase as it would in a straight tube.

As the heights of the liquid columns suspended in the tubes are precisely in the inverse ratio of their densities, their weights must be exactly equal. Under these circumstances, as it is known that the atmospheric pressure will sustain, on the average, a column of mercury 30 inches in height, it will also sustain a column of water about 34 feet high, since the specific gravity of mercury is 13·56. But as the pressure of the atmosphere varies within a range of 3 inches of the mercurial column, the height of the column of water will also vary proportionally, or within a range of 3 feet 5 inches nearly. The atmosphere itself must exercise a pressure of 15 lbs. on every square inch, or the weight of a vertical prism of air 1 foot square on the base is about 2160 lbs.

It is to the pressure of the atmosphere that the ascent of water in a tube, from which air is exhausted, is owing. The removal of a certain portion of the air causes that which remains in the pipe to dilate, its elasticity then diminishes, and the liquid rises in the tube until the weight of the column thus raised and the elasticity of the dilated air balance the external pressure of the atmosphere. It follows that, for the same dilation of the air, the liquid will rise to a height which will be in the inverse ratio of its density.

It must be evident, from what has been said above, that the height of a liquid column of any description might be taken as the measure of the weight of the atmosphere. But it has been found more convenient to adopt mercury as the standard of comparison, because it admits of the column being made shorter than for any other liquid; and also because it is not so likely to give off vapours (whose elasticity would to a greater or less degree falsify the indications), as the majority of liquids are liable to do. Even mercury itself gives off a vapour, but, within the ordinary range of the temperature, its elasticity is so small that it may be

cted without inconvenience. In the arts, then, we find almost invariably, tubes in which columns of mercury ee to move, according to the weight of the atmosphere, sed to ascertain the pressure of the latter, and are known e name of barometers.

engineering the barometer is principally used for obserns upon the weather, or for ascertaining comparative ides. As these subjects are, however, more particularly ed in the Number of this Series especially devoted to matics, the student who might desire further information e use of the barometer is referred to it, or to the works at the end.

is a necessary consequence of what has previously been d, that when a gas is compressed, it diminishes in bulk, s its elasticity increases with its density, it must sooner ter arrive at such a state of condensation, that the elastic shall be equal to the pressure exercised; but the laws ing the condensation and the elastic force are yet but imperfectly known. Practically, and especially in the of atmospheric air, it may be considered that the presexercised by a gas against the side of the vessel which ins it, is increased in precisely the same proportion as pace which it occupies is diminished; or, in other words, elastic force of the air, or of any gas, is proportional to ensity. It must be observed, however, that a variation e temperature will affect the conditions of elasticity; use an increase of temperature will give rise to an ine of elasticity without, or even in spite of, any variation e density.

e consequence of the elasticity of gases is, that they ise a pressure upon their containing vessels independent y mechanical, or external, pressure, and in this respect differ from ordinary fluids. The energy of this pressure nds upon the difference between the elasticities of the ined and the surrounding gas, independently of any ure which may be applied to the former.

Pneumatics are more immediately connected with the practice of civil engineering in the principles regulating the construction of pumps and syphons. Pumps are of several descriptions, and every maker has his own peculiar fancies with respect to their details; but the only real distinctions, at least of such pumps as usually are made with a view to employ the atmospheric pressure as far as possible, are the suction and the forcing pump.

The suction pump consists of a vertical pipe immersed in water at the lower end; of a piston moving in a portion of the cylinder; and of two clacks, or valves, one of which is seated upon the pipe, and the other upon the piston itself. If in such a pump, of the construction usually adopted, we suppose the piston to be at the bottom of the cylinder, and nearly in contact with the lower valve, upon raising the former, the valve upon the piston itself will be closed by the weight of the atmosphere, and a partial vacuum will be formed under it. The air in the pipe and the barrel of the pump will become rarefied, and unable, therefore, to press upon the surface of the fluid immediately beneath it with the same force that the external air presses upon the water in the vase; the latter force being then no longer balanced, a column will be raised in the pipe whose height will depend upon the atmospheric pressure, and the perfection of the vacuum. If we further suppose the water to rise to a certain height in the cylinder, and that the piston then descend to the position first assumed, the air between it and the water will escape through the valve, and the water will still further rise in the pump, until at last the piston plunges into it, and the water rising through the valve is retained above it by closing the latter, which is made only to open upwards. On the return up-stroke the water above the valve is raised by the piston to the outflow, a second vacuum is created beneath it, and a further portion of the water in the containing vessel is made to enter the pipe by the atmospheric pressure.

The height of the lifting pipe we have seen to depend

on the perfection of the vacuum created, nearly as much upon the atmospheric pressure. Instead, then, of being able to raise water about 34 feet, as we should be entitled to expect theoretically, it is very rarely that suction pumps can be made to work at greater heights than from 16 to 28 feet; and in all such machines the chances of diminished effect increase with the dimension of the pump itself. In practice the height is usually made about 24 feet; and the diameters of the suction and ascending pipes are usually made from $\frac{1}{6}$ to $\frac{2}{3}$ of that of the pump barrel. It is necessary, in order to secure the greatest results from such pumps, that, when the piston descends, it should touch the lower clack, so as not to leave any space between the latter and the under side of the piston. The power to be applied to the handle must be in excess of the sum of the weights of the column of water above the piston, and of the column in the ascending pipe, and also be able to overcome the friction of the various movements of the machinery.

The forcing pump may be either a *lifting* pump, when the column of water is raised directly upon the piston, or a *forcing* pump, when the water is driven by the piston into an ascending pipe. It is usual to combine the suction pump with both of these varieties of the forcing pump, in order to use the atmospheric pressure as far as possible.

Evidently any kind of pump, in which the whole weight of a liquid column has to be set in motion at each stroke of the piston, must be so disadvantageous that it will not be matter of surprise that the ordinary lifting pump should rarely be used; nor will it be worth while to dwell upon it here, further than to say that it is, in fact, nothing more than the suction pump already described, the upper tube of which has been prolonged. The forcing pump consists of a barrel and a suction tube, separated by a clack, opening upwards into the barrel. The piston, instead of carrying a second clack, is solid, and the clack is placed at the entrance of the ascending

pipe, which usually branches from the barrel in a horizontal direction for a short distance, and then ascends vertically. The motion of the second clack is from the barrel outwards.

The action of such a pump will be analagous to that of the suction pump, until the water rises into the barrel from the atmospheric pressure; because the piston will rarefy the air beneath it, and the unbalanced pressure upon the containing reservoir will cause a column of water to flow into the tube. When the water has entered the barrel, at the next down stroke of the piston, the latter will cause it to force open the foot valve and to rush into the ascending column. The pressure of the water in this column must act upon its base with a weight proportionate to its height, and if then a motive force be employed in excess of this pressure, the water can continue to be lifted to a height proportional to the supposed motive power.

In those suction and forcing pumps in which the water does not rest upon the piston, the effort necessary to raise the latter is only that which would be required to raise a weight equal to that of the column of water raised by the suction. But in descending, the piston compresses the water, and causes it to pass through the foot valve and to rise in the ascending column; and consequently it requires a power able to move the weight of the latter. There must evidently be a great advantage in equalizing these actions, which it is always easy to do, when the total height to which it is required to raise the water does not exceed 56 feet, by merely placing the pump barrel in the middle. Beyond this point, it becomes necessary to adopt mechanical arrangements to communicate greater power to the descending than to the ascending stroke of the piston. It is in such cases that the application of steam power produces some of its most useful results.

The piston of forcing pumps was formerly always made of wood, or of metal, packed with leather so as to work closely against the sides of the barrel; but latterly the *plunger*

pumps have been more generally used. The *plunger* is a metallic cylinder, either solid or hollow, and of a length a little greater than that of the stroke; the diameter being from $\frac{1}{2}$ inch to 1 inch less than that of the barrel. The packing is fixed, and is in fact formed by the stuffing box. The plunger in descending takes the place of the water which it drives before it; and in ascending it creates a vacuum in the suction pipe.

In any pump, theoretically, the useful results would be represented by the formula $Pm = Wh$, in which we have

Pm = the motive power employed;

W = the weight of the water raised; and

h = the height to which it is raised above the well.

Practically, however, the effect is diminished by the friction of the packing, of the piston rod, and of the column of water against the sides of the various pipes; the weight and the friction of the clacks diminish the effect, as also must the variations of the direction and velocity of the ascending column, to which the velocity of the stream at the point of discharge must be added. In the most perfect pumps it is possible that $Wh = 0{\cdot}75$ to $0{\cdot}85\ Pm$; but ordinarily the coefficient of useful effect rarely attains 0·75.

Several machines depending upon pneumatical principles are used occasionally in hydraulic engineering, such as the diving bell, camels, floating docks, &c.; but their details belong so much more especially to other branches of practical mechanics, that it may suffice here merely to allude to them. But the application of the motive power of winds to land drainage is often of so great economical use, that it may be advisable to dwell upon it somewhat more in detail.

Smeaton, in a paper communicated to the Royal Society, 1757, drew up the following table of the velocity and perpendicular force of the wind in different circumstances:—

Miles per Hour.	Feet per Second.	Perpendicular Force on One Square Foot, in Avoirdupois Pounds and Parts.	
1	1·47	0·005	Hardly perceptible.
2	2·93	0·020	Just perceptible.
3	4·4	0·044	
4	5·87	0·079	Gently pleasant.
5	7·33	0·123	
10	14·67	0·492	Pleasant, brisk.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36·67	3·075	
30	44·01	4·429	High wind.
35	51·34	6·027	
40	58·68	7·873	Very high wind.
45	66·01	9·963	
50	73·35	12·300	Storm, or tempest.
60	88·02	17·715	Great storm.
80	117·36	31·490	Hurricane.
100	146·7	49·200	Hurricane, tearing up trees and overthrowing buildings.

A wind below the velocity of 10 miles per hour is not able to insure the working of a corn mill; when the velocity exceeds 20 miles per hour, it becomes necessary to furl the sails. This last velocity is considered to be the most suitable for the purposes of navigation.

According to Smeaton, a windmill yields the greatest effect when its sails are made with inclined surfaces, the generating lines of which, situated at points obtained by dividing the length of the sail into six parts, form with the axis of the wheel, or the direction of the wind, the angles indicated in the following table. (The generating line, No. 1, is that which is the nearest to the axis, and it is at this point that the sails begin.)

Angle with Axis.	Angle with Plane of Movement of the Sails.	Observations.
72°·00	18°·00	The angles of the third column are the complements of those in the second.
71·00	19·00	
72·00	18·00	
74·00	16·00	
77·50	12·50	
83·00	7·00	

usual to make the width of the sail vary between $\frac{1}{5}$ of the length, and never to exceed $\frac{1}{4}$ of that dimension. m the same authority it appears, that when the sails of are well filled the velocity of their extremities without l is equal to four times that of the wind; and that it is sary that the velocity of the extremities should be 2·5 7 of the velocity of the wind, in order to obtain the mum effect. The useful effects produced are in the of the cubes of the velocity of the wind, and may be esented by the formula $P = \frac{v^2 a^2 \sin^2 \theta}{440}$, in which $P =$ the ılse in pounds avoirdupois; $v =$ the velocity in feet per nd; $a^2 =$ the area of the sail in feet; $\theta =$ the angle to direction of the stream.

n Holland windmills are extensively used for the purposes lrainage, and it is there the practice to employ one mill, ı sweeps of from 80 to 90 feet diameter, for every 1250 ıs, and for a lift not exceeding 5 feet. These mills work, on average, 60 days in the year, and raise a total quantity of ,220,000 cubic feet of water 1 foot in height. Further ıils connected with this portion of engineering operations be found in the next chapter.

The syphon depends upon the atmospheric pressure for power of action, and is employed so frequently as to

warrant an examination of its principles in this place. It consists of a bent tube, open at both ends, one branch of which is plunged into a reservoir. If such a tube be filled with a liquid of any kind, the elastic force of the atmosphere may practically be considered to be in equilibrium on both sides, because the difference of level between the two branches is never sufficiently great for any appreciable inequality of pressure from this cause to affect the motion of the fluid, which, under such circumstances, must be entirely owing to gravitation. Now, the liquid columns in the respective branches have a tendency to fall away from either of them; but this cannot occur, for directly a void is left in the upper portion a considerable difference takes place in the atmospheric pressure; so that as long as motion exists through the tube, it must take place in one direction. Consequently, if one side be longer than the other the liquid will flow through it, and the pressure of the atmosphere upon the surface of the liquid in the vase will keep the tube full until the level of the fluid in the vase descends to that of the opening of the shorter branch. It is evident that the syphon can only act within limits varying with the densities of the fluids to which it may be applied; thus, for water, it would be impossible to make it act beyond a height of 34 feet, and this theoretical limit is rarely attained in practice.

There are many other phenomena connected with Pneumatics, of great general interest, and even of frequent useful application, such as those connected with the movement of gases in pipes, aerostation, sound, evaporation, distillation, &c., to some of which it will be necessary to refer hereafter in the consideration of the practical details of Hydraulic Engineering. In the mean time, should the reader require further information upon the subjects contained in these preliminary remarks, he is referred to the Treatises of this Series on Hydrostatics, &c., Pneumatics, and to the list of authors to be found in the appendix.

Drainage and Irrigation.

The functions of vegetable life cannot be carried on without presence of a certain quantity of water, inasmuch as the ids which circulate in their tissues are almost entirely nposed of the water taken up by the roots from the ground. ith the exception, however, of some aquatic plants, the jority suffer from an excess of humidity; and when water found in an agricultural district in large quantities, it is injurious as its absence is in other cases. Thence arises necessity for *draining* lands surcharged with water, on one hand; and for *irrigation*, on the other. It is equally portant that air should be allowed access to the roots of nts; but the operations of ploughing, harrowing, hoeing, , by which this object is effected, belong to the science of iculture rather than to engineering.

The causes of the excess of moisture in any particular trict depend upon the rain-fall, the natural configuration the land, and the nature of the surface and the subsoils; l, conversely, the same causes influence the dryness of er districts.

The distribution of rain is very unequal, not only when ge divisions of the globe are considered, but also over y confined areas. This is a natural consequence of the s affecting the production of rain; for it is caused, firstly the heat giving rise to evaporation, and then the winds ry the vapour to a distance, until it is precipitated, either contact with the cold earth, or by meeting with another s of air so much colder as to absorb the heat which holds moisture in solution. In the tropical regions, the rain- is greatly in excess of that of the temperate zones; from the greater uniformity of temperature, it also pens that the fall is confined within a much more limited e of time; the total quantity is greater, but the number ainy days is less, and the law appears to prevail that the ber of rainy days increases with the latitude. But local

circumstances modify these general laws to a great extent; so much so, that in nearly the same parallels of latitude one district may be subject to frequent floods, whilst another may be constantly or periodically exposed to droughts.

The quantity of rain, for instance, is always less in plains than in elevated table-lands, especially when the latter are connected with mountain chains. On the sea shore also, it is greater than in inland districts, because more vapour rises from the sea than from the land. The existence of particular currents in the ocean will at times give rise to an excess of rain on the shores round which it flows, an instance of which may be cited in the gulf stream which causes the great rain-fall in the southern and western counties of England and in Ireland. The prevalence of certain winds will augment or diminish the quantity of rain, according to whether they blow over surfaces able to affect in any way the amount of evaporation. Thus, in Europe, if the wind blew always from the north-east, it would never rain; whilst if it always blew from the south-west, the rain would never cease on the sea coast. It is to these various causes we must attribute the local differences between the number of rainy days, which, in the instance of Ireland, are about 20 out of the total 365; in that of the greater part of England, France, and the north of Germany, they vary from about 15 to 155 rainy days in the year; and in that of Siberia, it is stated that the number falls to 60. Nor are the quantities falling less variable than the number of the days, for we find that the total quantity registered near London is, on the average, about 24¾ inches per annum; whilst near Plymouth it is about 38 inches; at Manchester, 37½ inches; at Seathwaite, 140·6 inches; at Glasgow, 33½ inches; and near Edinburgh, at Glencorse, in the Pentland Hills, 36¼ inches.

The natural configuration of the country affects the amount of moisture retained, by the greater or less facilities it may offer for its removal. Evidently, a district presenting sharp declivities on every side, with few depressions to hold water

in pools, must not only throw off the latter with great rapidity, but also furnish few means of maintaining evaporation, when the fall of rain shall have ceased. The outline and direction of the watercourses also materially influence the length of time during which the water may be retained. And, indeed, the majority of cases in which marshes occur may be attributed to the physical causes connected with the surface of the earth; either, in fact, to the existence of a zone of surrounding country at a higher level, or to the existence of a watercourse in a similar relative position.

The natures of the surface and of the subsoils produce effects upon the humidity of a district which are more readily under control than the causes previously alluded to. They act either by retaining the surface waters, or by giving passage to the springs fed by lands at a greater distance; and it is of the utmost importance to be able to distinguish between these two sources of humidity, as the surface drainage adapted to the first, under some circumstances, is utterly ineffectual to remedy the second.

For drainage operations, the strictly correct geological descriptions of the various strata may be neglected, and they may be divided simply into two classes, the *porous* and the *impervious*. The former comprises all those consisting of loose materials which absorb water easily and allow of its passing freely, such as gravel, sand, loamy clays, and the comminuted upper strata of most of the limestone formations. The latter consists of stiff blue clays, or of the plastic clays found in such abundance; of some kinds of gravel cemented by argillaceous, calcareous, or ferruginous materials; and of such limestone, sandstone, or granitic rocks as present a close grain without any fissures. No regular order of superposition of these classes of strata exists in nature, and from their complication arise the greatest difficulties in drainage.

In such cases as those in which a pervious stratum lies upon an impervious one, the water falling from the clouds

permeates the former until it meets the latter. If, then, no escape be furnished for the natural overflow, the water must accumulate in the lowest depressions, until the hydrostatic pressure of that in the higher portions forces it to the surface [illegible] conditions of level may be [illegible]. It may frequently happen, that a natural overflow exists at a small distance from the surface, but not at such a depth as to prevent the existence of great moisture in the main body of the stratum, although no external indication beyond the character of the herbage may indicate the moisture. The great objects, therefore, in all drainage are, not only to remove the surface waters, but more particularly to cut off the subterraneous waters, which either rise to the surface or are confined beneath it.

The removal of surface waters is a comparatively simple operation, for it may be effected by dressing the land into ridges, and giving these an outfall into a drain or ditch all round the field. The ditch itself would pour its waters into any natural course, and the latter may at any time be enlarged or improved, by observing the principles regulating the flow of water in open channels, laid down in page 56, and subsequently, of this Part. The conditions to be observed being, that the channel should be able to carry off, at a suitable velocity, the maximum quantity of water likely to be thrown into it within a definite period; and that the velocity should not be such as to endanger the bottom or the sides. If the outfall drain be artificially made, it is, generally speaking, desirable that it should be impermeable.

Operations connected with the improvement of an outfall affect very large areas, and would seem almost to call for some action of the Legislature. In many individual cases, so to speak, it is beyond the power of one proprietor to undertake them; and the only course left open to him is, to isolate his own land by diverting any water flowing from other districts, and to remove that which falls upon his own, by means the most adapted to effect that object economically.

e execution of an intercepting drain will very frequently
fice to remove all the subterranean waters, should such
found, by stopping the flow of the latter in what would
erwise be their natural direction, and thus leave merely
rain-water falling over the particular district to be dealt
h. In such countries as Holland, and the fens of Lin-
nshire, Bedfordshire, &c., the intercepting drain itself
omes the outfall, and a means of communication; for the
in drains are used as canals, and the waters from the low
ds are pumped into them either by windmills or by steam
wer, as may be most expedient.

In hilly countries it rarely happens that any difficulty
urs from the direction or inclination of the watercourses,
l in them the question of outfall is not so complicated as
the lower and more level districts near the embouchures
rivers. The longitudinal section of the center line of
rly all rivers is, in fact, a concave parabolic curve, the
x of which is in the elevated grounds near its source.
e velocity, under such circumstances, is very great in
y countries, and the streams are able to keep their course
a tolerably straight line, if even they do not continually
d to rectify any bends which may naturally exist. But in
portion as the rivers approach the sea, or other large
ers, they usually flow through flat alluvial deposits, or
ough level plains of earlier formations. The velocity of
water diminishes, and the gradual deposition of matters
ught down from the hills raises the bed of the river,
ilst the direction becomes tortuous from the incapacity of
stream to overcome the obstacles to its progress. In no
ntry in the world can more striking illustrations of these
s be found than in England; nor, perhaps, is there any
ntry where well-directed works for the purpose of obvi-
g their inconveniences would be attended with more
liant results.

Before commencing any rectification of the bed of a river

or stream, it is necessary to inquire carefully into all the numerous commercial interests which are likely to be affected by the alteration. A plan of the existing watercourse and its various affluents, with longitudinal and transverse sections of the beds and banks to a considerable distance on either side, is required; observations upon the flood and summer levels, and upon the seasons and duration of the changes in the volume of the stream, must be made; and, lastly, a careful notice must be taken of the nature of the materials carried down, the mode in which shoals are formed or the banks destroyed, and the nature of the river-bed in its normal state.

If the stream follow a very tortuous course, a new channel in a direct line evidently will shorten the distance between its extreme points, and increase the inclination of the water line. The velocity of the stream will be proportionally augmented, and if the same quantity to be discharged flow before and after the execution of the new channel, its sectional area may be made smaller; or if, on the contrary, it be made of the same area as the original channel, it will be able to discharge a greater volume. Any sudden bends may thus be avoided; but it is to be observed, that there seems to exist some law, the cause of which has hitherto escaped our analysis, owing to which rivers are not able to flow in straight lines for any great distance, in other than beds of masonry, without requiring great and frequent repairs. At any rate, every stream when left to itself, so to speak, assumes a tortuous outline; and, from the experience obtained in France and Italy, it appears, that after a deviation there is always a tendency to resume the original directions, especially during the seasons of floods. It is, therefore, preferable that the center line of a new channel be formed with a series of curvatures of very large radius, rather than in a perfectly straight line. Upon the Rhine it was found that the river exercised no corrosive action upon

banks when the radius of curvature was about 2750 yards g, the bed of the river consisting of sand and gravel, and ng frequently exposed to sudden and violent floods.

The efficient action of new channels can only be attained observing these conditions:—Firstly.—They must be epened as much as possible; the sectional area to be given ll of course be regulated by the volume to be discharged der all the varying conditions of the rain-fall. Secondly.—ey must not present any sudden projections, or form any arp curves with the main stream. Thirdly.—If the new annel cannot be dug out at once to the required depth, it ust not be opened to receive the waters until the *down* ream end of the old channel be closed, so as effectually to rce all the running water into the new channel. Fourthly.—All obstacles, such as trunks of trees, large blocks of stone, c., must be removed, so as to leave the watercourse per-ectly clear.

When an entirely new outfall is to be formed, the di-mensions to be given to it must depend upon the proportion f the rain-fall it may be required to carry off. This will ary, not only according to the configuration of the country, ut also according to the greater or less degree of perme-bility of the materials. In precipitous mountain districts he rain flows off with comparative rapidity, merely from the nclination of the ground. Should, however, our observations e directed to particular mountain districts, it will be found hat the discharge from granitic rocks differs very materially from that from the lias, the oolites, or the clay formations. From the granites, the rain runs off nearly as fast as it falls, for the materials are non-absorbent, and the subordinate out-lines do not present any depressions likely to retain the water. The lias is also, comparatively speaking, impermeable, as are lso the clays; whilst the oolites and the gravels absorb he water during the period of its falling, to give it out gain when perhaps the supply may have ceased. In fact,

the character of the discharge from the granites, the lias, and the clays, may be regarded as being of a torrential description, whilst that from the limestones is far more equable. In the former districts, it appears that about $\frac{2}{3}$ of the rain flows off in the natural watercourses, whilst in the latter and in the gravel the maximum quantity so flowing would only be $\frac{1}{3}$. Again, the proportion of the rain-fall which may require to be carried off will differ, according to the greater or less continuance of the rainy season. Thus, in winter it happens that the ground frequently becomes saturated with water at an early period, and it is advisable in such a case that any flood should be carried off as rapidly as it rises. The maximum quantity of rain which may fall within a given time becomes then a condition regulating the dimension of the outfall, of nearly as much importance as the average fall of the whole year.

An outfall having been secured, either by adopting or improving the natural facilities of the country, or by forming a new watercourse, if the source of the water deteriorating the quality of any land be not such as to be removed by surface drainage, an investigation of the surrounding district must be made, to ascertain the superposition of the strata, their nature, thickness, and respective inclinations; or, should any local circumstances prevent this examination from being carried out on a sufficiently extended scale, small ditches or trial shafts should be sunk at the upper and lower sides of the district to be drained. The points of outburst of any springs must be noticed, and, if possible, their sources of supply be discovered. When these points are settled, the direction to be given to the drains must be considered; and, if possible, it would be advisable to make them follow the line of the longest fall of the ground. The depth, and the distance apart of the drains, must depend to a certain extent upon the description of crops to be raised, but more particularly upon the nature of the subsoil. For, in the first

e, it is necessary to place the drains at such a depth as bviate any danger of their materials being deranged by cultural operations. In ordinary modes of cultivation, minimum depth to which the ground is worked may be en at 8 inches; in many others, the ground is moved a depth of 18 inches; and for these reasons it is usual place the drains at such a depth that there shall be a ance of about 20 inches between their highest points and surface of the ground. In the second place, if an imperable subsoil be met with within a distance of 5 or 6 feet n the surface, such as to intercept the passage of the water either direction, the drains must be carried down to it; or erwise the portions between each of them would only be perfectly dried. The nature of the materials employed l also modify the depth of the drains; for if they be bulky, in the case of broken stone, they must require a greater th than when tiles or tubes are used.

The width of the trenches will be regulated by the depth the drains, because the workmen require a greater space work the deep than they do the shallow ones. At the face the width is required to be greater than at the bottom; l in practice it is found that, for a depth of about 3 feet, it ufficient to give a width of about 1 foot at the surface and 6 inches at the bottom; for a depth of about 4 feet, those nensions become respectively 1 foot 4 inches and 8 inches; ilst, for a depth of 8 feet, they become respectively 2 feet nches and 1 foot 2 inches. The direction of the drains uld be made as straight as possible, in order to avoid interference with the discharge of the water; and they st be commenced by opening the lower portions of the trict first.

It is indispensable that a regular inclination be given, and t it should be sufficient to insure the flow of the water. A of about 1 in 200 will be found sufficient for ordinary s, especially if the drain tiles be well laid.

There are several modes of filling in drains employed by

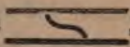
Fig. A. Fig. B. Fig. C.

agricultural engineers, the principal of which are represented in the subjoined sketches. Fig. A represents a simple and economical system followed in countries where tubes or stones are expensive. It consists in forming shoulders upon the sides of the trenches, and laying upon them a thick sod with the grass downwards, the remainder of the trench being filled in with the materials thrown out from it, taking care to reject the denser and more impermeable earths. This description of drain is economically formed, but it does not last for any length of time, at least with sufficient efficacy.

Fig. B represents an economical form of drain for countries in which large quantities of water are to be removed, and where stone is cheap. The channel is formed by placing thin slabs on edge, leaning against one another, and covering them with broken stones or gravel; the whole is then covered by sods and the lighter earths of the excavations, as before. If the waters draining through such channels do not contain any notable proportion of soluble salts, which they might gradually deposit around the broken stones, they will continue to flow for an indefinite period.

Fig. C represents the tile and shoe drains, which were much employed in England formerly, each tile being about 14 inches long, by 3 or 4 inches wide, and 4 or 5 inches high, and the shoes being of the same length, but a little wider than the tiles. Of late years, however, it has been the opinion of agriculturalists, that perfectly cylindrical tubes are the most advantageous, not only on account of the greater facility of their manufacture, but also of the greater economy in

fixing. These cylindrical tubes are made of the same h as the earlier descriptions of tiles, and of diameters ng from 1 to 3 or 4 inches.

hen the soil is peaty, or a running sand, or when nature of the materials through which the excavation rried is such as to render it difficult to form and main- the bottom of the trench in a perfectly straight line, butting joints of the tubes will require to be protected by rs, which may be perforated with numerous small holes. ler ordinary circumstances, it will suffice either to use s with an end terminating thus , or merely a straight end. In the last two cases, the trench should y be thrown out to the precise width necessary to receive pipes; and in both it is absolutely necessary that the ightness and the uniformity of inclination of the bottom the trench be rigorously observed.

Drains should not be made too long, because, if the fall be at there would be danger from the bursting of the pipes the head of water; and the chances of choking are con- erably increased, as well as the difficulty and expense of pairs. It is advisable to make the subdrains pour their ter into a species of main of larger diameter, which sub- quently should pour the collected stream into the general tfall. Mr. Parkes recommends that the submains should ver much exceed 300 yards in length, and he usually akes the diameter of the lower half about $\frac{1}{6}$ greater than at of the upper, in order to insure the perfect discharge the water. Under ordinary circumstances, however, it is eferable that the smaller drains should discharge into an en ditch, because the water would flow away more easily, d at the same time the repairs are performed with greater cility.

The length of the main drains may be greater, on account their greater dimensions, but the condition above stated, giving them an enlarged diameter at their lower ex-

tremity, must be observed. They are formed in the same manner as the subdrains, but, of course, in the lowest parts of the land; and it is advisable to place them at a slight distance below the subdrains, in order that these may discharge more freely. Their inclination must be greater, because the volume of water they have to transmit is also greater than that of the subdrains; and it is important to carry them at some distance from the hedges, or large trees, lest the roots should force their way into the pipes and choke them, because these are known to have a remarkable avidity for water, and are likely to force their way into the joints of the pipes. Lastly, it is important that the junction of the subdrains with the mains should not take place at right angles, but in an oblique direction, so as to avoid any interference with the velocities of the respective currents which might be likely to cause the deposition of any sand or mud in suspension in either of them, For the same reason it is advisable, that two drains coming from different parts of the land should not be made to converge at the same point.

The distance apart of the drains will depend, in fact, upon their depth, and the degree of permeability of the soil; and this becomes one of the most important questions to be decided before commencing such works, for the greater the distance, evidently, the less will be the number, and the cost of the operation. Mr. Smith, of Deanstone, advocated the system of numerous drains, at comparatively shallow depths, whilst Mr. Parkes recommends that they be made deeper and at greater distances. The former made his drains from 6 to 8 yards apart, and about 3 feet deep; whilst the latter makes the distance from 13 to 20 yards, and the depth from 4 feet 6 inches to 8 feet. In fact, both parties may be in error in striving to enforce their respective systems too rigorously, and a course of proceeding which may be eminently successful in one case may be very inadvisable in another. Thus, if a stratum of permeable materials exist, whose depth

y be 6 feet, it is possible that a drain placed 5 feet below surface may withdraw the waters from a distance of about or 15 yards on either side. In such a case, there would a decided advantage in placing the drains at the greatest ths and distances, according to Mr. Parkes' plan. But if soil itself be light, and at a depth of from 2 to 3 feet from surface an impervious subsoil be found, it would be dently absurd to carry the drains below the subsoil, because s would entirely destroy any lateral action of the drains yond a distance of about 6 or 8 yards. In such cases, the stem recommended by Mr. Smith is the more advisable; d, indeed, it happens in this particular branch of en- neering, as in all others, that every individual case requires be judged of and decided upon its own merits.

In Ireland the usual system latterly adopted appears to be admirably suited to the class of materials most commonly et with, that an abstract of it is subjoined.

Minor drains are formed at distances apart varying from to 40 feet; the depth is made 3 feet from the lowest point the surface; the width, from 15 to 18 inches at the top, and inches at the bottom. These minor drains are parallel to one other, and only run from 150 to 200 yards without falling to either a ditch or a submain. In these drains a depth of inches of broken stones, 2½ inches in diameter, is placed, re being taken that they be quite clean; a sod 3 inches ick is placed over them, and the earth is filled in. Some- mes pipes 2½ inches in diameter are inserted.

The submains are cut 42 inches deep, by 20 inches wide at e top and 12 inches wide at the bottom; they are carried ong the low side of the field, about 10 feet from the fences, d are not allowed to run more than 300 yards without dis- arging into a covered or main drain. An open channel, nches square, is formed, and above this the trench is covered d filled in, as before, with a thickness of about 8 inches of oken stones, carefully cleaned.

The open main drains are sunk to a depth of at least 5 feet;

found to be that of the drains. The outfall must be mad usual.

In the second illustration a boring, or borings, as may required, are to be made through the impermeable stratum the pervious one upon which it reposes; or, in fact, a se of absorbing wells are to be formed, and the various surf drains made to converge to it. In the Treatise upon W boring and Sinking much information will be found connec with the principles of the action of such wells and their m of construction. In these instances they will serve to c the waters from the various surface drains into the lo strata, which almost invariably will be found to possess s natural outlet, at a greater or less distance, in the shape spring.

When the succession of strata outcropping upon a hill is more complicated than in the cases above supposed, an such as to produce an alternation of dry ground and ma the class of works to be executed may require to be somew different in detail, but in principle they will be found to similar to those described. The object to be effected is, in cases, to form a new outlet for the water; and whatever cou be adopted, it must be based upon the ordinary principles hydrodynamics applied to the particular configuration of locality, which, again, can only be ascertained by a care examination of the geology of the district. This examinati may very frequently require to be extended over a considera area, because the sources of supply of any springs may found to exist at great distances, and until all the conditi affecting them are ascertained it is impossible to adopt a other than empirical methods of obviating their effects. N withstanding, then, the progress of science in our times, M Elkington's rules may still be quoted as being the simplest a most effective for the execution of the drainage of ma lands formed by the outburst of land springs. They are follows:—

t. To find out the main spring or cause of the mischief.
nd. To take the level of the spring, and ascertain its sub-
neous bearings.
rd. To use the auger to tap the spring, when the depth of
drain is not sufficient for that purpose.

t must be evident, that if any district be situated so as to ive the waters flowing off from surrounding eminences, it eventually be converted into a morass unless an outlet be ided. Should the district be small, this object may be cted, as before, by the formation of absorbing wells placed he lowest points; but when its dimensions are considerable, first operation to be performed will consist in forming a h all round the marsh, so as to intercept the waters flowing n the upper lands, and at such an elevation, and with such ll, as to insure the discharge of any waters which may be red into it either from above or from below. The banks, s, and bottom of this ditch must be formed of impermeable erials. The ground contained within these banks must be drained in the ordinary manner, and the drains made onverge to a point from which their waters may be withvn, either by means of an absorbing well, or by some meical contrivance, such as water-wheels, steam-engines, or lmills, setting in motion pumps, norias, or Archimedean ws.

f the marsh be owing to the existence of a river at a er level, it must be treated in a similar manner to that described, if the river itself cannot be diverted; or the r must be confined within impermeable banks, and the rs draining from the low lands poured into it by some of above-mentioned engines. It may, however, happen that stream traversing the marsh may be subject to great and en floods; and in such cases it is necessary to form a le row of banks, of which the outer ones must be placed distance and superior elevation sufficient to carry off the ased volume of water flowing through them at such ds. The first banks then serve to contain the river in

[illegible]

[illegible] will serve to contain [illegible] may be devoted [illegible] follows [illegible] the [illegible]

[illegible] water in any of the [illegible] apply [illegible] screw [illegible] will [illegible] water-pressure engin[illegible] pumps [illegible]

Of these the pump [illegible] effective when large of water are to be raised from great depths, but it is [illegible] to the objection that the maintenance of the packing piston and of the pump-barrel must be very expensive, the water to be raised is so much charged with earthy as must always be the case with that flowing from drai[illegible] therefore the height to be overcome does not exceed 15 fe usual to adopt other machines. Thus in Holland the medean screw is mostly used, when the height vari 7 to 12 feet, and in the majority of cases motion i municated by windmills; when the height varies from 6 inches to 7 feet, however, flash-wheels are employed. own fen districts, the scoop has been applied by Mr. W burn, with remarkable talent and success, in cases wh height to which the water had to be raised varied fro 15 feet. In the East the noria (a machine consistin endless chain bearing a series of buckets, dipping i water at the lowest point of its course, and pouring it it passes the upper point) has been used from time imme The fifth class of machines enumerated above are so used for drainage purposes that it is not worth while t upon them at present. Indeed, local circumstance modify so considerably the ground of the choice of or other of these mechanical means of removing wat it is dangerous to attempt to lay down any general la

e subject. The price of coals, the motive power of a neigh uring stream, the more or less favourable position of the cality so far as the action of the wind is concerned, the price labour, and an infinite number of other details, may differ greatly in any two given cases as to render very different odes of action necessary, or at least advisable.

Perhaps the most gigantic operation undertaken for the rpose of draining lands receiving the waters from other stricts is the one connected with the drainage of the Harlaem Ieer; and although it is rarely that engineers are required operate upon so large a scale, a description of the method lopted is subjoined, because in principle it is identical with at required even in smaller operations of the same de- cription.

The Harlaem Meer, or lake, owed its origin to the excess f the rain-fall over the evaporation from the district around , so that the waters, accumulating in the depression forming he lake, spread annually to such an extent as to absorb of ate years about 150 acres of its former banks. In the be- inning of the sixteenth century the area was considered to ave been about 9140 acres; in 1839, when it was decided attempt the drainage of the lake, it had increased to nearly 5,000 acres, with a mean estimated depth of about 13 feet. The works are being executed by the Dutch Government, who expect to be partially repaid by the proceeds of the sale of the land.

The first operation consisted in the formation of a channel for the purpose of isolating the waters of the lake from those of the surrounding country, and at the same time of serving as an outfall for the waters to be raised. This channel is about 37½ miles long, with a width varying between 125 and 138 feet, and with a depth of 10 feet, and gave rise to great difficulties owing to the want of materials fitted for its con- struction. Even now it cannot be said to be impermeable, and the filtrations through it must ever remain a cause of expense and probable danger. Three large steam-engines,

of about 400-horse power each (nominal), raise the waters from the lake into the canal, and are stated to be able to discharge about 238¾ cubic feet per second. They are single-actioned engines, working expansively, upon the Cornish principle, and give motion to a series of pumps working at a single lift. Two smaller machines, of about 200-horse power each, are used occasionally to discharge the water from the intercepting channel, when, owing to any extraordinary tides or high winds the natural flow from the latter is interrupted. These machines give motion to a series of flash wheels, which raise the water about 3 feet 7 inches.

The pumping was commenced, upon a large scale, in the month of March, 1849, and in August, 1851, the water in the lake had been lowered 10 feet 2 inches. It was expected that the remaining portion would be removed within a few months, and that the drainage of the bottom, and the consolidation of the banks would then be rapidly executed. The cost of these works was estimated to be, when complete, between 600,000*l.* and 680,000*l.*, or, at the higher estimate, about 15¼*l.* per acre.

In Ireland, some large bogs have been drained upon the system adopted in reclaiming the bog of Allen, by withdrawing the water from below, and in this case it was attended with considerable success. The surface was firstly divided into fields of an oblong figure, and of about 5 or 6 acres area by open drains. Auger holes were driven at distances of about 33 feet down to the rock, and at a level of at least 1 foot above the surface of the water in the drain. Curved pipe tiles, 1½ inch diameter, were inserted into the holes, so as to throw the water into the centre of the drain. These drains were made about 6 feet deep. On the Chat Moss drainage, no effort was made to withdraw the deeper-seated waters, but all the measures adopted were designed merely with reference to those flowing upon the surface. Square enclosures were formed, 100 yards long by 50 wide, by means of large open drains, 3 feet 9 inches deep at the minimum, 3 feet wide at the top, and 1 foot 8 inches at the bottom. Covered cross drains were

rmed, communicating with the open ones, and with a width between 12 and 14 inches as far as the shoulder, placed about feet 2 inches from the surface; below which point they were rried to a further depth of about 16 inches, with a width of inches: these cross drains were placed at distances of about yards from center to center. No tiles or pipes were used, e bottom of the drain filling being formed by the surface it raised from the moss.

It frequently happens that large tracts of alluvial deposits re found at the mouths of rivers, which are alternately co-ered or left bare by the tides, and which, generally speaking, ontinue to increase until they attain such a height as only to e affected by the spring tides. These banks then become overed with a species of marine vegetation, and are cut up nto innumerable small creeks, which, at the low-water, serve s channels for the inshore streams. Many banks of this escription have been reclaimed from the tidal action, both in ur own country and in Belgium and Holland, with such ignal advantage, in many cases, as to cause regret that others hould still remain unproductive.

The works usually required to reclaim these foreshores onsist, firstly, of an embankment forming an enclosure to protect them from the sea, which must be able not only to resist the hydrostatic efforts of the external waters, but also the more destructive action of the waves and the currents; secondly, of the system of drainage of the enclosed lands, including under this head occasionally the arrangements for introducing waters charged with fertilising matters, an operation performed in some districts, and known locally by the name of "warping."

The enclosure banks are made, generally speaking, from 2 to 4 feet above the high-water line of the equinoctial spring tides, with a minimum width of from 3 feet 6 inches to 7 feet at the crown. The outline of the bank in plan must depend upon many local circumstances; but, theoretically, it will be found to offer the greatest resistance to the normal action of the

waves if it be convex seawards, whilst the stability of the ma terials, if it be executed in stone rubble, will be the greatest i the outline be concave. Whatever be the form given in plan it must always be borne in mind that no sharp internal angle should be allowed, and that every projection must be joined int the body of the work by gentle curves of the largest possibl radius.

The best form of the sea slope is a subject still much i discussion amongst engineers. On the shores of Hollar and Belgium the practice has been, for many years, to make rectilinear, and inclined at a small angle to the horizo Although these slopes have succeeded in some positions, the are others in which the results obtained have been precise of an opposite character, and in which it would appear that vertical wall would have been preferable. Again, many di tinguished engineers are of opinion that the best form to given is one similar to the outline the materials themsel would assume if left to arrange themselves by natural caus whilst latterly Colonel Emy has advocated, with considera ability, the theory that a concave transverse section was t most fitted to resist the action of the ground waves.

Long fore slopes possess the advantage of allowing t employment of any sand, or other similar materials; th offer the least resistance to the action of the sea, and precisely the less exposed to injury in proportion as th inclination is greater. It has been observed that the destr tive action of the sea exercises its greatest effect about level of the lowest high tides of the neaps. But if th long slopes possess some advantages, they are accompan by corresponding disadvantages; for they conduct the wa to much higher points than they would otherwise reach, a it is not always that either the materials at hand or the sp disposable are such as to allow of their economical executi to which consideration, after all, the decision as to works this description must be referred.

Vertical inclosure walls occupy the least space, and exp

e smallest surface to the action of the waves; and these ;ain, instead of breaking upon the shore, are reflected towards e open sea. But walls of this description must encounter e maximum effort of the waves, wherever these do strike, d their recoil must act very injuriously upon the footings, less they be of a very resisting description. The concave alls recommended by Colonel Emy have not yet been tried a sufficient number of cases to justify any definite con- usions as to their merits; but they are in many cases ob- ctionable on the score of the ground they require, and the eat expense, not only of the first cost, but of the repairs.

The reasons which should influence the choice of the form be given to the sea slope of an embankment may be re- med as follows. 1. It will be influenced by the main rection of the winds, waves, tides, and currents, which ould be made to strike the bank as nearly as possible in a rection normal to the surface of the facing. 2. By the aterials to be procured in the neighbourhood. 3. By the rface of land which can be devoted to the formation of a ank. 4. And principally by the commercial considerations fecting the original execution, the maintenance, and the alue of the whole operation.

The inner slope of the banks will depend upon the ma- erials of which it is composed; and at its foot a catch-water rain must be formed to collect the waters falling upon the

Enclosure of Zind Plas.

nclosed land, and to conduct them to the outfall. The Dutch ngineers usually make the slope about 5 to 1, and they form roadway about 20 feet wide between its foot and the edge of e catch-water drain. When the bank is formed of mud or

silt, it is necessary to carry up in its center a core of sand or other hard substance, to prevent rats or moles from boring through it; and means must be taken to cover the exposed surfaces with vegetation of a character to bind together the materials of which the bank is made.

The land waters collected in the outfall drain are let off by means of sluices, whose apertures will be regulated by the quantity to be discharged, and the duration of the period in which the flow can take place, as well as by the head of water which may exist at the commencement of the discharge. Upon the sea coast the intervals between the tides recur with great regularity; but in the upper portions of river-courses the casual floods are likely to prevent the discharge during periods of variable duration, so that in many such positions it is very probable that the reclaimed lands may be partially, or entirely, flooded on all such occasions: the cultivation to be adopted must be regulated with a view to these contingencies.

The simplest mode of closing the outfall drain is by a sluice upon hinges, fixed at the outer end of a culvert, in wood, masonry, or iron, passing through the body of the bank. The floor of this aqueduct is placed at the level of the bottom of the catchwater drain, and it has an inclination outwards. So long as the head of water upon the outside of the sluice is greater than that upon the inside, it will remain closed; directly the waters upon the outside have fallen so as to form a sufficient head upon the inside to overcome the friction of the hinge, the sluice will open and give passage to the waters. It is, however, advisable, that a sliding gate working in a valve be placed behind the hinged sluice, to guard against the possibility of accidental derangements of the latter.

Another description of gate frequently used in these works is the gate working upon a vertical axis and shutting against a rebate, in which the areas of the two portions of the gate are made unequal. When the waters on the outside are higher than those on the inside, the gates are pressed against

rebate; when the opposite conditions occur the gates
n and afford a passage to the land waters. Sometimes in
ge gates of this description when two leaves are employed,
y are made to meet at an obtuse angle like the leaves of
ck gate.

The system of warping is much practised on the banks of
Humber in our own country, in Tuscany, in the valleys of
Chiana and of the Rhone; and indeed the cultivation of
valley of the Nile is but an illustration of it upon a very
ensive scale. It is founded upon the principle that the
ers carry, in their downward course, the earthy matters
y derive from the lands surrounding their watersheds.
e waters so charged are allowed to flow over the land to be
rped, and they are retained upon it until the earthy matters
deposited, when they are allowed to run off by means of
rface weirs.

It is usual to surround land proposed to be thus treated by
embankment, in which are placed the inlet sluices, at the
west level. The water enters through these sluices at the
ghest point of one tide, and is retained during the interval
tween two successive tides; to be then run off entirely,
en from the ditches, before the influx of the next. Upon
e banks of the Humber it is considered that the most bene-
ial effects are produced by the execution of this operation
tween the months of June and September; the embank-
ents are made from 3 feet to 7 feet high, and it is usually
lculated that a sluice, with a clear water way about 6 feet
igh and 8 feet wide, will suffice to warp a surface of from
0 to 80 acres. In this district it is found that the warped
nds are at first cold and raw, and that they require a
eculiar treatment for agricultural purposes. Thus, they
re not favourable for the growth of corn; oats may succeed
pon them, but barley never will. The rotation usually
dopted is as follows:—The new warp is sown with grass for
wo years; on the third year wheat is sown; on the fourth,
eans; and on the fifth, wheat again. Should the ground

thus warped be found to contain too much salt, it must exposed to the air for some time before being brought in cultivation; and at all periods it is found to be objectional to allow the salt warp to deposit upon growing grasses. I deed, in Yorkshire, it is customary to let the newly-warp land lie fallow for twelve months before sowing the grass, a to let on the waters after the second crop of wheat has be raised.

The quantity of sediment brought down by the rivers fal ing into the Humber is enormous. Lord Hawke stated, his Report on the Agriculture of the West Riding, that tide would deposit an inch of mud, and the source fr whence it is derived is still a matter of great uncertainty. its mouth the Humber is as clear as most rivers, and t floods from the upper countries, so far from increasing t quantity of matters in suspension, on the contrary exercis very injurious effect upon them. In the driest seasons a the longest droughts it is found to be the best and most pl tiful, and produces its effect totally irrespective of the subs In fact, a new soil is formed, and the operation of warp differs in this respect from ordinary irrigation, which acts improving the soil already existing.

THE DRAINAGE OF TOWNS is a subject of such mani interest to the community at large, that the discussion of best and most efficient system to be adopted has occupied attention of legislators and engineers at all times. Th are two branches of the subject which may be considered be sufficiently distinguishable from one another for the p poses of classification, and which may be, and often treated in practice upon very different principles. Th subdivisions are—1st, the consideration of the means removing surface or drainage waters; and, 2nd, of the co deration of the means of removing all excrementitious m ters in such a way as to ensure their most effectual remo without annoyance, and their economical adaptation where possible.

Wherever a large and highly-civilized community assem-es it becomes frequently difficult to separate the two classes matters to be removed, especially as existing municipal ar-ngements complicate the question in an infinite number of ays. Cities grow, without much apparent reason for the rticular manner in which the increase affects their plan; ry rarely, indeed, is it possible to predicate, and to provide r, the eventual wants of their population; not only because e distribution of cities may alter, but also because from me to time changes are effected, even in national habits, hich defy all previous calculation. Thence it is that we find th the want of systematic arrangement in our own country, d the excess of it in France, equally sources of difficulty the adaptation of modern refinements. But we have at ast this advantage—that having done little, we have less to ndo; and, after all, it appears to be the wisest course to al with these questions as they arise, without endeavouring restrain the freedom of action of those who are to suc-ed us.

However, in all modern cities the tendency certainly is to vert house sewage into the public drains, especially in our own ountry. There are still many towns in which the old system f drainage for surface waters, and cesspools for house refuse, revails; but, compulsorily, they are diminishing in number very year. There are some conditions which render it oubtful whether the concentration of the two systems in the ame discharging drains be desirable, at least under all cir-umstances; and in this, as in all other branches of engi-neering, no inflexible rule can be said to exist. Owing to the nature of the soil upon which a town is built, its configura-tion, the character of the outfall, and of the country round that outfall, a course highly advisable in one case might be objectionable in another. These modifying causes will be xamined successively; stating before so examining them the general conditions to be fulfilled. Some of these consider-

F 3

ations will be found to apply to the discussion of the questi
connected with the water supply of towns.

The conditions required to be fulfilled are, as before stat
that the whole of the surface and land waters be remov
and that the house refuse be carried away effectually and
offensively. The latter will depend, in quantity, upon
population, and the greater or less abundance with wh
water is supplied for domestic use. In England, it is only
exceptional cases that the average number of inhabitants
house exceeds 6; whilst in France and some parts of S
land it may be occasionally as many as 40. Upon a copi
distribution of water being effected, it is usual to calcul
that every individual would give rise to a consumption
about 20 gallons per day; and probably of this total quan
about 16 gallons may find their way into the sewers from
various dependences of houses. Sewers, then, if designe
remove all waters, must be of sufficient capacity to disch
a volume calculated upon the above supposition, together
any storm-waters which may fall. It has been observed
Mr. Phillips, that the greatest flow of house sewage t
place between the hours of 11 and 1; and that in eac
those hours at least $\frac{1}{8}$th of the total daily discharge find
way into the sewers. The capacity of the latter must, t
be made such as to discharge the greatest quantity of st
water falling in one hour, supposing it so to fall when
house drainage also furnishes the greatest volume.

The soil upon which a town is built may influence
character to be given to its drainage, either as it may fa
or impede the transmission of what are called land spri
Thus, in many parts of London, and also in the tow
Southampton, there exist small elevations, the surfac
which consists of an impermeable brick earth, lying up
stratum of gravel and sand, this last again capping the
blue clay known as the London clay. In many other c
the upper stratum of brick earth is wanting, and the gr

rms the immediate surface stratum; whilst in others, again, th are wanting, and the London clay is entirely exposed. he drains and sewers to be laid in between the points B and C, such a formation as is represented, need not be made of a eater capacity than is required to remove the surface or the use waters supplied by the district; but those to be laid tween C and D, and still more those between D and E, must able to receive the waters filtering through the bed of avel. Near London, the exposed surface of gravel is

enerally so small that the water yielded by it does not quire to be taken into account; because the dimensions iven to the sewers to enable them to carry off storm-waters re more than sufficient to relieve the strata traversed by these prings, which are necessarily characterized by a certain degree f regularity in their flow. At Southampton, however, the xtent of superficial gravel is, proportionally, infinitely greater; nd it is found that, after a continuance of wet weather, the hole of the lower portions of the gravel become charged ith water to such an extent as to inundate all the basements elow the level of the natural ground, unless where large ewers are formed, so as to intercept the flow of the subterranean waters.

In some parts of Paris the same phenomena occur upon a larger scale and with greater regularity than in the cases above cited. There a considerable portion of the city is built upon what formerly constituted a marshy plain, between the river nd the hills of Belleville and Montmartre. The lowlands re situated upon a calcareous formation, called geologically 'the lower fresh-water limestone," which allows the water to nfiltrate with great difficulty; and the several hill sides are uccessively formed of the gypseous deposits, with their asso-

ciated marls, capped by a deep stratum of sand and sandstone, occasionally covered by the upper fresh-water limestone. In the direction towards Belleville the sands occupy a considerable breadth of country, and receive a copious supply of water during the rainy seasons. At the same time the various hills present steep escarpments, so that the storm-waters, falling upon them, flow away with great rapidity. It follows, from these combined circumstances, that in order to obviate any inconvenience from these respective sources, the intercepting culvert, executed along the line of greatest depression, has been formed of much larger dimensions than the area it immediately drains would appear to require, without, however, preventing the occasional flooding of the lower parts of this quarter of Paris.

If the geological structure of the soil of a town in some cases appear thus to increase the difficulties connected with its sewerage, there may be others in which it produces precisely opposite results, so far at least as the removal of surface waters are concerned. Thus, in Weymouth, the portion of the town constituting the ancient Borough of Melcombe Regis, is constructed upon what is, in fact, the shingle bar thrown across the mouth of the Wey. All that is required, then, to remove the surface waters, is, to form openings through any paved roads or courts—absorbing wells, in fact—and the waters immediately sink to the level of the sea. In some parts of Liverpool, also, advantage is taken of the absorbent nature of the gravel, to allow the surface waters, to soak into it; for the drains are occasionally executed, in the lower portion, of bricks laid dry, whilst they are only set in mortar in the upper portion.

The configuration of a district, meaning by that term the general conditions of its division into subordinate districts of hill and dale, will also influence the system of sewerage to be adopted, insomuch as it may affect the number, dimension, and direction of the main sewers. New and distinct outfalls may be required for the several portions, and, fre-

quently, according to the final mode of disposing of the sewage, distinct establishments may be required for its preparation.

The influence of the outfall is very great, for it may easily be conceived, that if a system of sewerage be made to discharge into a watercourse flowing always in one direction, as in the case of all cities situated upon rivers above the tidal range, provided the outlet be so situated as to insure a constant flow, no necessity can exist for providing against an accumulation of the sewage waters. But in tidal rivers, it frequently will occur that the mouths of the sewers will be blocked up by the rise of the tide, for intervals, varying of course with the peculiar laws of the tides in the precise locality, and with the levels of the mouths. It becomes necessary in such cases to construct the lower ends of sewers so discharging, of sufficient size to admit of their containing the waters at any time likely to flow into them during the intervals of their suspended discharge; and also to make them of sufficient strength to resist the hydrostatic pressure of any accumulation in their more elevated portions. It is to be observed, that the above reasoning only applies in those instances where the sewage is poured into the rivers directly, without being in any manner usefully applied, either in the arts or in agriculture.

The quantity of storm-waters flowing from any given district within a given time, has frequently been alluded to as one of the most important elements in the determination of the size of the sewers. It is naturally very variable, not only according to the latitude of the localities considered, but also according to particular seasons of the year: it depends, in fact, upon the frequency and the violence of sudden atmospheric changes, rather than upon the average state of the weather; and, as the sewers must be constructed so as to carry off the maximum rain-fall, the ascertaining accurately what the latter may be is an indispensable condition for the determination of their capacity.

In the commencement of this Section, the ave
tribution of rain in different localities was treated
summary manner. It may suffice, then, at prese
serve, that torrential rains occur with the greatest f
in countries near the tropics, but that higher latitude
no means exempt from them. At Rome, where the
annual fall is about 2 feet 8 inches, showers have
served of 17 hours' duration, with a total fall of not l
5 inches. At Marseilles, in a shower of 14 hours'
13 inches of rain have fallen; and at Arles, in 1
nearly 8 inches. At Southampton, the greatest fall w
been noticed is about 2 inches in 10 hours; whilst in
as much as 6 inches of rain have fallen in 1½ hou
latter observation would appear to have been influe
some very exceptional phenomenon, perhaps of the c
of a waterspout; but it appears, from numerous o
servations in England, that storms of a similar natur
mentioned as observed at Southampton, are of su
frequent occurrence to justify the assertion of the r
"when sewers are constructed to carry off storm-wat
should be of a capacity to discharge a proportion of
rain-fall in 24 hours, varying according to the char
the district."

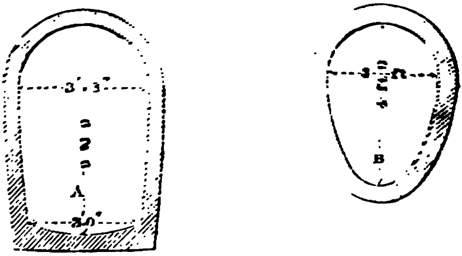
The proportion so flowing into the sewers will
upon whether the district be rural or urban; and,
latter case, upon its configuration and the degree
meability of the soil. It is usually calculated, that
open country about ⅓rd of the rain-fall finds its way
into the natural watercourses; in ordinary countr
about ⅔rds are estimated to flow at once into the
and, perhaps, in large densely-populated towns, it w
safer to calculate upon ⅘ths of that quantity as li
reach them.

If a demand existed for the application of sewage
to agricultural purposes, and if a sufficiently copiou
old supply existed to insure the flushing of the dr

ıld unquestionably be [illegible] to keep the two classes of
rage distinct, [illegible]
ıntities of storm-water must [illegible]
the quality of the sewage [illegible]
ıjudicial to its [illegible]
be difficulties attending [illegible]
the present state of [illegible] and engineering science;
l, notwithstanding the [illegible] of some modern
horities, who from their position might fairly have been
ected to exercise greater reserve and [illegible], all the
empts to apply liquid sewage [illegible] have been hitherto
st signal economical failures. The separation of the two
sses would produce in many cases an additional advantage
m the fact of the smaller sectional area required for the
vers, and, consequently, from the increased fall, or, where
t could not be obtained, from the greater elevation at
ich the outlet might be established.

The form to be given to sewers may sometimes require
be different from what it is at others, owing to the ne-
sity which may exist to visit and cleanse those which have
t either a sufficient fall or a sufficiently copious supply
water to keep themselves clear. The only invariable rule
be laid down upon this subject is, that "the wet contour
ould be made to bear the smallest possible proportion to the
tional area," for the simple reason that the friction is
ays in the direct ratio of the surface upon which it acts.
follows that, wherever it is possible so to execute them,
vers should be made of a circular section. For house
vers there can be no difficulty on this score, because the
roduction of the tubular drains has furnished not only the
st efficient, but the most economical, means of execution.
e only remark which appears to be required on this subject
ears to be that, at the present day, the tendency is to
cute them too small; and that there is danger of their
king if used of less than 4 inches in diameter. For
ndary main drains the same system of tubes may be

applied to a certain extent; but when the length becomes considerable, there will be found so many probabilities of obstruction, and so great danger from the accumulation of gas evolved from the water, that it is very questionable whether tubes should ever be used without the formation of side entrances for their examination and repair at maximum distances of [illegible] of a mile, or without frequent opportunities of communication with the atmosphere. Contrary to the fashionable theory, it may perhaps be more advisable to construct a main drain, intended to receive several secondary mains, of sufficiently large sectional area to allow of its being visited and repaired without entailing the necessity for opening the ground. The form of main sewers adopted in different countries varies, as may be seen from the annexed sketches,



of which A represents the section of the main sewers used in Paris; B represents the section lately adopted in our own metropolis. The former is more convenient for the operations of workmen, whilst the latter is certainly less likely to require cleansing, because the scouring action of the water is made to operate more forcibly upon the materials brought into the sewers.

Whatever be the form of sewer adopted, the dimensions should always be calculated so that it should be able to discharge the maximum quantity it can ordinarily receive without being more than half full. The inclination to be ven to house sewers should be, at the minimum, 1 in 144,

r 1 inch in 12 feet; that to be given to submains, also at the inimum, 1 in 480, or 1 inch in 40 feet; whilst the inclination be given to main drains may occasionally be carried as r as 1 in 2300, although it is decidedly preferable to keep ithin the limits of 1 in 1000. All junctions should be ade so that the axes of the secondary sewers should be ortions of circles tangential to the axes of the main sewers, nd of the largest radius it is possible to obtain. Side ntrances should be formed as closely as possible to the oints of intersection of the respective sewers.

The collection and disposal of sewage must, evidently, from hat has been said before, be entirely guided by the demand r the materials so obtained; and, hitherto, they have all een wasted in England. This is the more to be regretted, ecause in France, Germany, Belgium, and Italy, the manure o allowed to run to waste in England is found to be highly eneficial, and in our own country all manures are expensive. Near Edinburgh some attempts have been made to apply he sewage, by irrigating meadows with the water from ewers, yet the results there obtained are far from such as re likely to guide us in the selection of any general course f proceeding. The mode of application at Edinburgh is tated, in fact, to be very objectionable, on account of the oul smell given off; and it is also to be observed, that it rarely happens that any extent of meadow land can be found near large towns, under the necessary conditions of level to allow of a similar application by mere gravitation. Fairly, the disposal of sewage is the great problem still to be resolved by all parties connected with this branch of engineering; the very injudicious assertions of the advocates of certain theories have hitherto only indisposed the public mind to its examination.

In the case of Edinburgh, the storm and house waters were conducted together upon the meadows irrigated by the sewers. It was found, however, that there was too much anure in the contents of the latter, and it became necessary

to form catch ponds, in order to enable it to deposit; and it must be borne in mind, that in the days when these ponds were formed (1829), the habits of the Scotch people were not such as to cause the bulk of the house manure to find its way into the sewers. The grass from these meadows was cut from four to six times a year, a result so little surpassing what might have been obtained by ordinary irrigation, that there is little reason to induce any person to incur a large outlay in order to obtain similar privileges. In the neighbourhood of Milan nearly the same results were obtained, for the waters of the Naviglio Grande, which receive the small quantity of house sewage continental habits allow to flow into watercourses, were found to be too rich at first, and after deposition not to produce much greater results than those derived from any other stream, so far, at least, as grass lands were concerned. Upon corn lands, the application of the comparatively highly-diluted manure of sewers seems to be of very questionable advisability, whilst, at the same time, it is to be observed, that the price of land in the immediate neighbourhood of large towns rarely allows of the cultivation of what may be called bulky crops.

It appears that the common sense of the disposal of sewage matters consists in obtaining the deposition of the fertilizing properties they may possess, and in securing them in the most portable form. The great difficulty to be overcome lies in the ammoniacal salts, which no system hitherto proposed has succeeded in obtaining in a permanent form. The use of lime water may cause the precipitation of organic matter, but the salts of ammonia in sewage waters usually exist in the condition of the carbonate, and there is not a sufficiently preponderating affinity between the lime and the carbonic acid gas to cause the latter to quit its combination with the ammonia to join the lime. Perhaps the use of the sulphate of lime or the sulphate of iron might be attended with more satisfactory results.

In France, the system adopted in dealing with the whole

estion of sewage of towns, is, to separate the rain and rface waters from those derived from water closets. The ter description of sewage is collected in cesspools, made impermeable as possible, and from which it is extracted enever required; or it is collected in large casks placed cellars and communicating with the soil pipes. The connts of these different descriptions of cesspools are carried large lay stalls at Montfaucon and Bondy, and allowed the former to settle in vast basins or reservoirs, two in mber, with a close dam between them, so that one may be ed whilst the other is being emptied. The liquid upon the p of these reservoirs is drawn off by sluices, and passes ccessively into not less than seven other basins, in which it treated in various manners, for the purpose of causing the eposition of any matters in suspension. The area of the pper reservoirs is about equal to $2\frac{1}{2}$ acres superficial, with a epth of about 12 feet; the area of the lower reservoirs is bout equal to $13\frac{1}{4}$ acres. From the last of these the waters re allowed to escape into the main sewer running through he low lands at the foot of Montmartre. At Bondy, the ystem of dealing with the manure is in principle similar to hat employed at Montfaucon; and in both, the solid matters deposited at the bottoms of the reservoirs are placed in the open air to dry into powder, before being used.

Such also is the mode of dealing with sewage in use nearly all over the Continent, and to a certain extent, far too great, even in our own country. Anything more economically absurd, or more injurious to public health, it would be difficult to imagine; and, excepting that some use is made of the manure, the whole system may be cited only as a model to be avoided. Cesspools are always objectionable, because they retain a permanent source of infection wherever and however constructed. The operation of cleansing them is always disgusting and injurious, whilst the foul exhalations from the depositing reservoirs contaminate the air to a great distance around. Add to this, that, in the

again, the best results are obtained from those called *nat*
and, as they are almost the only ones adopted in our cou
the following remarks will be confined to them.

The period of the year in which the water should be po
over the land will vary with the latitude, and the purpos
which it is to be applied. In England it is used somet
for the express purpose of protecting the vegetation from
effects of frost, and is therefore applied in winter; but
be desired to retain the matters in suspension in the wa
they should be used in the later part of the autumn an
the early spring, because it is at those epochs of the year
rivers are the most charged, under normal circumstan
The usual practice in the south-west of England is, to irri
through the months of October, November, December,
January, from 15 to 20 days at a time, without intermis
At the expiration of each of these periods, the ground is
to dry during five or six days. If a slight frost should o
the water is again immediately turned on, but the grou
left dry if there be any probability of a long-continued
severe frost. In February the length of the periods of
gation is diminished to about eight days, and care is tak
shut off the water early in the morning, so as to allow
ground to dry during the daytime, and thus obviate
danger from the light frosts at night. In March the
precautions are observed, and the periods of irrigation
dually diminished, in such proportions that the ground
be thoroughly dry before the end of the month. The mea
are then depastured during the month of April by sheep
lambs, and eaten barely down before May by a heavy s
After that the grass is allowed to stand for hay, and in
districts it is usual to irrigate for a week before it is so
but, as an invariable rule, it appears that when the gra
two inches high no more water is applied.

Occasionally the lands are irrigated after the crop of
has been carried; but it is asserted that the grass of
aftermath is, under such circumstances, very injurio

p. Grass lands irrigated in summer are known to uce the rot in those animals, though cattle are not affected similar manner. It is known, also, that if the purest r remain upon land for any length of time, especially in ng or summer, it deposits a species of white scum, of the istence of melted glue, which acts very injuriously upon qualities of the grass.

'ery little is known with respect to the quantity of water ired to irrigate a definite surface; and indeed this must end upon many circumstances connected with the latitude the district and the nature of the subsoil. In the south France, it has been calculated, an acre of meadow land ld require about 1200 cubic feet of water per day during season for irrigation; but there the land is very light, l the ground, owing to the summer heats, is very dry. In gland it is almost certain that, even upon tolerably light ds, it would not be necessary to employ much more than lf the above quantity. In the county of Gloucestershire the actice is, to allow a stream of two inches in depth to flow er the surface, and to dress the latter with a fall of half an ch to a foot from the feeder to the drain.

The primary conditions for the establishment of a system irrigation are, that a copious supply of water exist at all nes, and that the land to be irrigated should present such a figuration as to allow the waters to flow over it with a gular current, and to insure a perfect discharge of the water er it shall have passed over the land.

The water may be poured over the land either by means of am across the whole width of the channel, or by a lateral iation, according to the water privilege of the landowner. former course is preferable wherever it can be adopted, ause it enables the water to be penned back, and thus red over a greater surface and upon higher points; but it ecessary to pay particular attention to the effects of such a upon the flow of the stream, in order to avoid flooding lands of neighbours. It must be borne in mind that the

most important of these is the hatch at the mouth of the conductor, which will require to be of considerable strength in order to resist the efforts of any sudden freshets; for if these should occur when the crop is in a forward state, and bring down waters charged with much sedimentary matter, they may produce very disastrous effects. The floating troughs themselves may be closed by movable dams, or merely by pieces of turf laid across the mouth.

All the above remarks must be considered as only possessing a very general application, and as being susceptible of variation according to local circumstances. Thus the inclination frequently given to the main conductors in the mountainous districts of the Alps, Tyrol, Savoy, Dauphiné, and Pyrenees, is $\frac{1}{500}$; whilst in the private canals lately executed in Piedmont and Lombardy, it varies from $\frac{1}{1600}$ to $\frac{1}{3600}$; and in La Provence it varies from $\frac{6}{10000}$ to $\frac{9}{10000}$. It would appear that in mountainous countries, therefore, the higher limit may be adopted; but that if the inclination approach $\frac{1}{350}$, it becomes necessary to retard the velocity of the stream by a series of cascades or dams, for there are few soils that could resist its denuding effects under such circumstances; and if the irrigation take place in a plain where the river has become tolerably clear, the inclination may be made as stated above, from $\frac{1}{1600}$ to $\frac{1}{3600}$.

In setting out the main conductor, it is important that the radius of curvature of the changes of direction be made as large as possible, in order to avoid any diminution in the velocity of the flow and the rate of discharge, and also to obviate any destructive action upon the banks. The minimum radius should be from 100 to 150 yards. The banks should be kept at least 8 inches above the water line when the supply is constant; and it is even desirable to make that height from 16 to 18 inches, to guard against any inconvenience from the development of aquatic plants, which takes place with most extraordinary rapidity in all such positions. The peculiar mode of growth of these plants, in long festoons, also produces a

ter interference with the rate of discharge than would from their precise volume; because they retard the city of flow, on account of the manner in which their long amers follow the direction of the current. It is important they should be cut as often as possible.

he establishment of gauges for ascertaining the quantity vater flowing into any conductor is an object of importance nany countries; but in our own, wherever water can be ined for the purposes of irrigation, it usually is to be met in such quantities as to render it unnecessary to take of the degree in which it is consumed. The subject has discussed in an article upon Water Meadows, in the de Mémoire to the Military Sciences," in which also will be d many formulæ besides those quoted above, which are n as being practically applied by the engineers of France Italy in the execution of this description of works.

t is necessary to construct waste weirs or overflows upon sides of the main conductor, especially when the stream which it is supplied is exposed to sudden and considervariations in its volume.

Vater may occasionally be obtained in sufficient abundance irrigation purposes from artesian wells; and many works his description have been executed in the northern parts taly and in France. In some cases the waters thus obed are eminently advantageous, because their temperature more constantly uniform than that of rivers exposed to ospheric influences can possibly be, and their chemical stitution is also frequently of a most desirable nature. In er positions it may often be advisable to procure the water uired by mechanical means; and under those circumstances or other of the various engines already mentioned, or to described in the next Section, may be employed, according he particular circumstances of the case. It may be necesy to observe, that the system of water meadows so much ployed in Devonshire is the *catch*-work meadow; and that y are formed by turning the water from a stream along the

side of the hill, through a small cut made nearly level, and stopped at the end. As soon as the cut is filled, the water flows over the sides; and, in order to regulate its velocity and equal flow over the whole field, small parallel cuts are formed at distances of from 20 to 30 feet, which, like the main conductor, are stopped at the ends. The water flows from these cuts in the same manner as before, over the intermediate beds, and is finally received into a main drain at the bottom of the field. Narrow deep drains run from the top of the field to the bottom, at right angles to the watercourses, and at distances of about from 50 to 60 yards, for the purpose of drawing away the water from the intermediate beds, when the operation of flooding is completed. Their ends are stopped, however, when the water is to be turned on.

It is generally considered that the first cost of preparing any large surface for the execution of bed-work irrigation is about 10*l*. per acre, although the Duke of Portland's celebrated water meadows cost as much as 30*l*. per acre. Catch-work irrigation costs, on the average, half the above, or about 5*l*. per acre. The maintenance of either varies from between 5*s*. to 10*s*. per acre; and in every instance, where water meadows have been skilfully prepared, and the supply of water is tolerably abundant, the rent has been at least doubled.

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THE

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PREFACE.

The lengthened delay which has taken place in the publication of the third volume has been occasioned by the small portion of time which my professional engagements have allowed me to devote to literary pursuits, and which time has been obliged to be divided between this and several other works. In order that no further delay should occur, I have relinquished the task of completing that portion of the present volume relating to Hydraulic Engineering to Mr. Burnell.

HENRY LAW.

6, Duke Street, Adelphi.
19th May, 1852.

In accepting the task of completing the portion of the deservedly popular Treatise on Civil Engineering which Mr. Law's engagements have forced him to decline, I would fain request the public to extend to me the indulgence usually accorded to those who find themselves called upon to endeavour to fill in an outline sketched by another hand. In this particular instance it has been my aim to confine my observations within the range of the synopsis inserted by Mr. Law at the commencement of the first volume. Insensibly they have far exceeded the limits he had proposed, and this branch of the work has attained a development perhaps greater than it merits in proportion to the remainder. But the very nature of the phenomena connected with Hydraulic Engineering is so complex that these appeared absolutely to require to be examined in detail, in order to arrive at a correct general view of the subject; and, lengthy as this portion of the Treatise may appear, it is to be feared that much has still been

A 2

omitted—many objects of study and investigation hinted at than explained.

To facilitate the researches of those who may be di to pursue the investigation of this most interesting bra the profession of Civil Engineering, a list of the celebrated authors who have treated of its details has annexed. The list is far from being complete, b contains the names of all who have fallen under my personal observation. I have drawn from many of sources largely, and have endeavoured to quote my auth when there seemed to be any originality in the observa Yet there are doubtlessly many instances in which I ma have acknowledged the full extent of my obligations. fact is, that, in the domain of the exact sciences, so discoveries have become public property, so to that they seem to form the staple of our know and to be used without reference to their authors. species of tacit consent, when a law has once been adn it seems that it is the right of the next comer to use i the same freedom as the discoverer; and so many suc are being every day added to our stock, that in th a kind of confusion prevails as to the parties to whom really indebted. It has, however, been my object in al to render honour to whom it was due.

Personally, I regret that the limits of the Treatise d allow a more lengthened investigation of the subject supply of water to towns, and the application of the s These are subjects so prominently before the pub present, and so many questionable doctrines have bee mulgated at the expense of the nation, with respect to that it behoves every engineer, as far as lies in his pow counteract the mischief it has been endeavoured to effe to recall the attention of the public to the real merits case. To do so completely would require another fiel a Rudimentary Treatise; nevertheless, even in it, th both room and reason to call attention to some of the th

ounded by incompetent persons. The misfortune in
land is, that if an investigation into any subject be under-
n, it is usually made in the manner so pleasantly
ribed by Beaumarchais, and "if a mathematician be
ired we take a dancing master;" or literally, if an
iry be made, and any subsequent measures adopted, in
ects connected with engineering, the parties it has lately
the custom to consult, are the omniscient barristers-at-
, not those who have devoted their whole lives to the
ly of the questions it may be desirable to elucidate. And
also to be observed, that the two professions of Engineer
Barrister-at-Law are precisely the only two learned pro-
ions which can be taken up without examination or di-
na. The remedy to so great an evil is hard to discover,
ss it lie in the freedom of the press. Unfortunately, the
n of the latter is slow, and much mischief is done before
public can be fairly roused to the consequences of fol-
ng the instructions of its blind guides. Nevertheless,
gna est veritas et prevalebit!"

GEORGE R. BURNELL.

4, Lincoln's Inn Fields,
July 15th, 1852.

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THE RUDIMENTS

OF

CIVIL ENGINEERING.

PART IV.

CHAPTER V.

SUPPLY OF WATER TO TOWNS.

THE questions which affect the choice of the source and means of supply of water to towns are those connected with the qualities of the water itself, in the first instance; and, in the second, the relative conditions of the difference of level, and the distance between the source resorted to and the place in which the distribution is to be effected. All waters, as is well known, are not equally adapted to domestic use; and those which are so adapted are rarely found in the precise localities where they are to be used; so that in almost all cases it is necessary either to bring the supply from a distance, or to raise them above their natural level.

Notwithstanding all that has been said in the controversy respecting hard and soft waters, there is still very great uncertainty as to the precise qualities required in those to be distributed in towns; and the public cannot be too frequently advised to hesitate before it adopts implicitly the opinions of men who, though neither engineers nor physiologists, have lately assumed to dictate upon the subject. Unquestionably excessive hardness is an objection to a source of supply; but

some of the chemical combinations which give rise to this characteristic, if they only act within certain limits, are stated by the most eminent authorities to render the slightly hard waters more adapted for human consumption than any others. Soft waters, again, are unquestionably more pleasant and agreeable for domestic use than hard waters; but their very softness may be owing to the presence of ingredients able to affect, slowly but surely, the physical organization of those constantly using them. Habit modifies the action of particular waters upon the human frame; and it is notorious that those accustomed to any one (whether soft, as flowing from the primary rocks, or hard, as affected by the carbonates or the sulphates of lime) are always seriously affected when they begin to use what would be universally considered a better water. Dogmatical assertions are as dangerous in this case as in all others; and, at least until competent authorities shall have decided what really constitutes the perfection of a water supply, questions of economical expediency must ultimately decide the course to be adopted in the majority of cases.

In the present state of uncertainty attached to this subject it may suffice to adopt the conclusions laid down by Thénard, and to pronounce those waters to be fit for domestic use which are fresh, limpid, and free from smell—able to boil vegetables without affecting their colours, and to dissolve soap without leaving curds. They should be very slightly affected by the nitrate of baryta, which will indicate the presence of the sulphates in combination; by the nitrate of silver, indicating the presence of the chloride of sodium; by the oxalate of ammonia, indicating the presence of the salts of lime; by the ferro-prussiate of potash, indicating the presence of salts of iron; or by the other chemical tests usually employed. The residuum, after evaporation, should be very small. A certain proportion of carbonic acid gas is considered to improve the digestive properties of water for drinking purposes; and nearly all physiologists, from the

ime of Hippocrates to the present day, assert that, in small quantities, the chloride of sodium and the bicarbonate of lime are also essential.

The temperature of water is of nearly equal hygienic importance with its chemical nature, and it should be as constant as possible; that is to say, compared with the atmosphere, it should be warm in winter, and cold in summer. Aeration is an important condition, for the oxygen thus communicated forms, in fact, an essential element of the salubrity of water. Vegetable and animal matters, either in suspension or solution, must be removed; not only because they are disagreeable in themselves, but also because they absorb the oxygen in suspension in the water, and cause the latter rapidly to putrify. The presence of this class of impurities may be detected by chlorine solutions, or by an infusion of gallic acid.

After all, the most efficient method of ascertaining the real qualities of a water supply is, to observe the effects it produces upon the organized life resorting to it, especially upon the human beings using it. Organized life is, in fact, a far more delicate test than any chemical agents can ever be; and it is eventually affected by impurities too minute to be ascertained by the grosser appliances of science. Such waters, therefore, as are habitually used by vigorous, powerful, and healthy populations, can never be pronounced to be unfit for domestic consumption, whether they be hard or soft, or whether they contain salts of lime, or salts of soda, or potash.

Rain-water, collected in the open country, or at sea, a short time after the commencement of a shower (for the first drops that fall carry down the impurities in suspension in the lower strata of the atmosphere), is the purest that can be obtained. In storms it sometimes contains nitric acid; on the sea-coast it is often brackish; at all times it is aerated, but flat, and insipid to the taste, and apt to cause colics, probably from the absence of carbonic acid gas. For industrial operations it is generally considered to be the most advantageous.

Snow water is without air, and usually deposits a small quantity of dust on being melted; ice water is bright and pure, but difficult of digestion. The loathsome disease, the *goitre*, is usually attributed to the use of snow water; but the healthy state of the crews of Captain Parry's ships during their long arctic voyages, when they had no other resource than the dissolved ice and snow, would appear to show that, if proper precautions be taken, they may be resorted to without inconvenience. Indeed, as several of the sources of soft water from the earlier secondary formations produce glandular swellings analogous to the goitre, it would be reasonable to infer that the latter must be owing to the matters contained in the snow, rather than to any qualities inherent in the waters derived from it.

Spring waters depend, for their qualities, upon the nature of the strata through which they pass. They are fed by the rain-fall soaking partially into the ground at a higher elevation, and finding its way to the surface at such points as offer less resistance to its escape than it meets in any other direction. As pure water, such as falls from the clouds, has a remarkable affinity for many of the earthy bases, and for the gases with which the latter combine, it must be evident that the springs will become impregnated with both, in proportion to the time they are exposed to their influence. Rivers, again, are formed by the confluence of springs and small streams fed by the drainage from the watershed; consequently, near their sources their waters must participate in the respective properties of the latter. In their course, however, they may acquire a degree of purity far greater than exists in the several affluents; especially if they run over a rocky or a sandy bed, and do not receive any organized matters draining from the lands they traverse. Much of the gas taken up by the springs in their underground course may be given off in this manner, and even many substances in a state of chemical combination may become separated. It is not, therefore, always true that the nearer the source the

er is the supply; but, on the contrary, so much do waters n gain by exposure to the atmosphere, that many physio-ists are of opinion that river waters are preferable to se obtained from springs.

The extent to which waters are improved by exposure to atmosphere must naturally depend upon the nature of impurities they may contain. Thus the carbonic, and netimes the sulphuric acid gases, are parted with easily, l the earthy carbonates deposed; but the sulphates of lime l the chlorides of calcium and magnesium are retained ich longer. Often the distinguishing elements of two eams may be traced for a considerable distance below the int of confluence; and, again, it may frequently happen it the impurities contained in either of them may facilitate deposition of those contained in the other. The greatest actical inconvenience attending the use of waters taken ectly from their source appears, however, to lie in this— it they are, under such circumstances, certain to depose ir earthy salts in the conduits employed in their distribu-n. Such waters as contain the bicarbonate of lime, or the lrous oxide of iron, are especially exposed to this objection.

Collection of Water from Surface of Ground.

The small streams collected from the watershed of a country st be affected by the considerations above described; that to say, their qualities must depend upon the strata over ich they flow, upon the organic matter carried into them, l their exposure to the atmosphere. It must be borne in nd, in all these discussions, that it is now generally admitted t, of the total rain-fall supplying the fresh water of a large t of country, one-third flows off in the shape of rivers ve ground, one-third is employed by the vegetation or in evaporated, whilst the last third penetrates the ground supply deep-seated springs and wells; or, at least, that

these proportions hold for the majority of cases. It is the former quantity, therefore, that must be calculated upon, in all cases where it is proposed to obtain a supply from the watershed of any particular district; at least, unless it be possible also to secure any deep-seated springs.

Now, it must be evident, that, as the streams from the watershed of a district are supplied by the rain flowing immediately off the land, they must vary considerably in volume; and that in winter, or the rainy season, they will be full, whilst in summer they will be comparatively dry. The variations in volume will depend upon the greater or less equality of distribution of the rain-fall, upon the configuration of the country with respect to the outlines of hill and dale, and upon the capacity of the superficial strata to absorb and retain water during wet weather, and to part with it during droughts—in fact, upon their capacity to store water, and thereby equalize the flow. All these combined causes have been observed to produce very great irregularities; and it becomes necessary, when a constant equable supply is to be obtained from a given watershed, to construct reservoirs so as to store the excess of one period against the penury of another. The dimensions of the reservoirs must depend upon the distribution of the rain-fall, and it may be laid down as a rule, that they should be calculated more with reference to the maximum demand and the minimum supply, than to the average of either. A capacity of storage equal to about six months' consumption, in addition to the quantity which is likely to be evaporated, appears to be the least which should be admitted when it is proposed to supply any agglomerated population in this manner.

Waters thus stored are much exposed to deteriorate in quality. They develop with singular rapidity both animal and vegetable life, and the decomposition of the latter, when in a state of decay, communicates elements of future combinations of the most repulsive and noxious description.

Such reservoirs must be filled necessarily with stagnant waters; and these, if exposed to the atmosphere, must also be exposed to the variations of temperature of the latter.

The following rules should be observed, wherever local circumstances will allow, in the construction of reservoirs: that the capacity be obtained by increasing the depth, rather than the surface; that the sides be as nearly as possible vertical; and that they be covered, so as to protect them from atmospheric influences, amongst which may, perhaps, be included the sun's light, for it appears to be the most efficient cause in promoting vegetation. The expense attending the execution of these works is so enormous that there can be but very few cases in which they ought to be undertaken; and, indeed, in all cases where covered reservoirs are required, very careful and elaborate comparative estimates of the cost of all other sources of supply should be made.

It may be interesting to state that the cost of some large canal reservoirs has been about 450*l.* per million gallons of water stored. No town reservoirs appear to have been constructed at a less cost than about 600*l.* per million gallons; whilst the Croydon Reservoir, the only covered one yet constructed, cost rather more than 4000*l.* per million gallons, including the price of the land.

A well-executed system of catch-water, or of thorough drainage, would unquestionably increase, to a remarkable extent, the quantity of water derivable from a given area, but it will in nowise diminish the necessity for constructing the storage reservoirs, but rather, on the contrary, augment it; for, necessarily, the storage capacity of the ground itself is diminished, in the direct proportion of the perfection of the drainage. The formation of a system of thorough drainage is also a very expensive operation; and, when combined with the necessity for reservoirs, it must lead to so great an outlay, that it may safely be asserted that the system of collecting water from what it has lately become the fashion to call

"gathering grounds" should never be resorted to, if any other can reasonably be adopted. However, it has been calculated that if the situation of the proposed gathering grounds offer steep declivities with narrow gorges, it is possible to obtain from it two-thirds of the total rain-fall—although hitherto no instance can be cited where such favourable results have been long obtained, for the efficiency of the drains becomes rapidly deteriorated.

Use of Springs.

Where springs, fed by the infiltration of rain-waters falling upon a large area, occur in considerable abundance, and of the requisite quality, they may be considered to offer the most desirable sources of supply in all highly-cultivated districts, because it is hardly possible to exclude drainage waters from flowing into superficial watercourses. The precautions, before alluded to, as being necessary to secure the deposition of the matters in solution which would otherwise choke the pipes, must be taken. It is also important to ascertain what is called the yield of the springs under all the varying meteorological conditions of the locality. Gaugings of any watercourse during two or three months are of very little use in cases of this kind, because the springs being supplied by the rain-fall it follows that they must vary with the variations of the weather. Unless observations, then, be extended over the whole cycle of the climate (in England, of about seventeen years' duration), the indications to be derived from gaugings over short periods are very likely to mislead in calculations with respect either to the average or the minimum flow. The period of the year when gaugings are taken will also materially affect the correctness of the observations, because not only does the rain-fall vary with it, but also the springs are observed to be affected at an interval of from one to five months, according to the nature of the strata. As the greatest quantity of rain falls during

the later autumnal and the winter months, it appears that, if it be necessary to confine the observations within very short periods, the most advisable course is to make them during the months of September and October; for, generally speaking, the springs are at the lowest about that period Even then, the indications are very likely to be fallacious, and, unless observations be carried over the whole cycle, the yield may occasionally fall far short of that calculated upon.

In the second edition of the "Treatise upon Well-Boring and Sinking" in this Series, the questions connected with the Theory of Springs are treated more in detail than can be done on the present occasion. It may, then, suffice to observe here, that springs are generally divided into two classes, land-springs and deep-seated springs, according to the structure of the district from which they derive their supply.

Land-springs are those fed by the waters falling upon loose permeable materials lying upon a retentive substratum, through the former of which they descend until the latter opposes their downward progress. As such waters are not under hydrostatic pressure, they cannot rise above the ground; but, on the contrary, they rush into any artificial depression in the upholding substratum. The majority of common wells are supplied in this manner, and are to be met with in almost every position. The waters they yield are, however, likely to become stagnant, deficient in aeration, and to take up any soluble salts existing in the ground or in the masonry lining their sides.

Land-springs are often met with in towns, as, for instance, in London, Manchester, Paris, Southampton, &c.; but from recent observations, it appears that, in all such cases, they are very much exposed to take up the nitrates produced by the decomposition of vegetable and animal matters in the ground, and are, in fact, often particularly unwholesome.

Deep-seated springs are those deriving their supply from the exposed surface of a stratum situated at a high level, then passing under an impermeable stratum, and lying upon

another impermeable basin-shaped deposit. The water, un such conditions, follows the levels of the lowest portions the permeable stratum, according to precisely the sa hydrodynamical laws it would obey if flowing upon the surfa Should an opening be made through the overlying imp meable stratum, the water will rise to a height correspondi with the hydrostatical pressure upon it, excepting insomu as it may be affected by the friction it meets with in traject, or by the existence of any natural overflow. The overflows frequently are to be found at the points where t permeable stratum passes under the impermeable one; a are to be accounted for by the fact, that, the lower bas being gorged with water, the fresh supplies, filtering throu from the more elevated districts, force their way out at t edge of the basin. Or, again, the overflows may be explain by the existence of a fault, or dislocation, of the strata, whi interrupts the subterranean flow of the water, by bringin perhaps, an impermeable stratum in contact with the edge the one holding water.

The chalk formation exhibits some very remarkable illu trations of these observations, and, in many places, it thro off springs of extraordinary beauty and volume. Thus, ne Amwell and Chadwell, in close proximity to the outcrop the basement beds of the London clay, are found the ce brated springs which gave rise to the New River, now, u fortunately, almost entirely supplied by the Lea. At Bu St. Edmund's a very powerful spring, called the Mermai Pits, is brought to the surface on the side of a transve valley, which appears to be attributable to a fault. N Southampton, the Otterbourne Spring rises at the point junction of the outcrop of the basement beds of the Lond clay with the chalk. Near Weymouth, the springs of Sutt Poyntz and of Upway are thrown up at the points wh the great fault of that peninsula affects respectively chalk and the oolitic formations. In the districts where carboniferous series are found, the effects of the faults

even more strongly marked; and, in the portion of the West Riding of Yorkshire near and round Halifax, an immense number of springs are given off at the points where the regular stratification of the beds is interfered with by the series of faults and upheavals, which have fissured and contorted the whole surface of the country.

Deep-seated springs such as these are naturally more constant in their volume than land-springs, in precisely the direct proportion in which their supplying strata are more powerful. It is, however, impossible to predicate what may be the quantity to be obtained from them, unless by a careful investigation of the area of the exposed surface, and of the conditions of level of the latter, as well as those of the ordinary water-line, and the other natural overflows of the district. Even these will not dispense with the necessity for gaugings, but they may prevent the absurd outlay which has sometimes been incurred in the endeavour to pump dry springs of this nature—a piece of folly actually performed of late upon one of the most copious of those above cited.

Artesian Wells are, in fact, nothing more than excavations through the overlying impermeable stratum supposed above to exist upon a permeable water-bearing stratum, underlain again by an impermeable one. They form, as it were, artificial outlets for the waters contained in the lower parts of the basin, and the water-line in them will depend upon the hydrostatical pressure existing upon the same lower parts. This, as said before, will be influenced by the level of any natural overflow which may exist around the edge of the retaining stratum. The conditions of success in an artesian well depend upon the perfection of the basin formed by the water-bearing stratum, so far as the mere retention of the water is concerned, and upon the level of the streams flowing from the water-bearing stratum, so far as the height of the water-line is concerned.

The quantity of water to be obtained from an artesian well must, therefore, be regulated by the area of outcrop of the

water-bearing stratum; and that it is far from being unlimited is proved by what has occurred at London, Tours, and Milan. There is also a consideration which ought to be borne in mind before commencing any work of this kind, or, indeed, before it is attempted to appropriate any deep-seated spring to the uses of a town population; and this consideration is, that the legislation upon the subject of underground watercourses is in utter confusion at the present day. Neither in England, nor in any other country, are there any fixed principles regulating the decision of the law courts upon this subject; and, in the only three cases hitherto submitted to our courts, it so happens that each one has been decided upon grounds reversing the principles of the former decision. Unfortunately, lawyers are rarely geologists or engineers; nor do engineers, when called upon to advise the lawyers, appear to have shown much knowledge of geology, so that the fortunate discoverer of a valuable supply of water, as the law stands, may see it intercepted by a neighbour who has quietly observed the results of his experiment; or he may find his only remedy to lie in an action, whose result must, above all others, be exposed to the "glorious uncertainty of the law."

The various physical conditions necessary to insure the success of artesian borings, also introduce great uncertainty in their results. Thus the well of Grenelle yielded a copious supply at the depth of 1802 feet; in the valley of the Loire several successful works have been executed, with an average depth of 500 feet; whilst one other, in the same district, of 628 feet in depth, and a second, 454 feet deep, were abandoned, after the usual retaining basin of the district had been traversed, on account of the absence of supply. At Calais, an artesian boring, 1150 feet deep, was made unsuccessfully through the chalk and subcretaceous formations into the carboniferous series. At Chichester, at a depth of 1054 feet from the surface, no water was obtained from the upper green sand; and at Southampton the boring was discontinued

at a depth of 1317 feet from the surface, being still in the chalk.

It would thus appear, after all, that the only infallible source for a water supply is to be found in rivers, although unquestionably there are often serious objections to their use. Thus it almost always happens that they receive the drainage waters from cultivated lands and inhabited districts; and the daily-spreading habit of making their beds serve as the outfall for sewage tends seriously to increase this evil. When rivers are resorted to, it becomes, therefore, necessary to place the supply-conduits at points beyond the reach of such sources of impurity, and, in almost all cases, to form settling reservoirs and filter beds, so as to remove the extraneous matters present in their waters.

It must, however, always be understood, that, in cases where any one course of proceeding has been recommended in preference to another (as, in this instance, it is stated that rivers offer the only infallible source), it is not intended to recommend its adoption to the exclusion of all others. There can be no rule in engineering, of this kind at least, from which it may not be advisable occasionally to deviate; and it is emphatically in this profession, perhaps more than in any other, that the economical adaptation of means to the end must ever decide ultimately the course to be adopted.

The quantity to be distributed in a town is usually assumed to be about at the rate of 20 gallons per head per day, calculated upon the whole population. This quantity would include all that is generally required for municipal and trade purposes, unless when the latter are of the character of cotton printing, dyeing, or scouring cloths, &c. In London, the supply is rather beyond that quoted above; in Paris, also, it is above 20 gallons; but, where accurate observations have been made, it appears that really the average daily consumption for every human being is about 7 or 8 gallons, and that in summer they require from 20 to 30 per cent. more than in winter. Municipal requirements vary, of course,

according to the habits of the country, but they rarely exceed 10 per cent of the total consumption; and ordinary trade purposes, together with the inevitable waste, make up the remaining quantity short of the 20 gallons per individual per day usually assumed to be required.

The parties considered to come under the designation of large consumers, and as such giving rise to an extraordinary demand for water, are manufacturers, tanners, fell-mongers, hair-washers, glue-makers, curriers, dyers, hatters, brewers, distillers, inns, bath-houses, and steam-engines. If many such exist, it will be necessary to provide especially for them; which, of course, would place the rate of payment upon a different footing from that to be applied to the public in general.

Mode of ascertaining the Amount of any Source.

The probable supply from any given source will be ascertained by direct experiment in the case of wells, whose hydrographical conditions may be unknown; or by a calculation of the areas and water-bearing capacity of the strata feeding them, should these be ascertained. It is important, however, in the former case, to make the trials at the season of the year when the underground flow is at the lowest, and to avoid any exaggeration in the estimate in the latter case.

Springs may be gauged either by causing them to flow into vessels of known capacity and observing the time required to fill these, or by causing them to flow through pipes of known diameters and observing the velocity; or, finally, by damming them up so as to destroy any initial velocity, and then allowing them to fall over a weir. The indications thus obtained must be affected, nevertheless, by what has been previously stated with respect to the causes of irregularity in their volume, so far as the rain-fall, and the structure of the beds from which they flow, are concerned. This subject, as well as that connected with ascertaining the volume of rivers and watercourses, has already been

ited in the introductory chapter of Hydraulics. The der is also referred to the observations upon the diffe-t sources of supply, for indications as to the means for ertaining the qualities of the water: it may, however, be well to observe, that inquiries of this description involve stions of delicate chemical analysis, and that, therefore, y should be always referred to the most eminent philo-hical chemists who can be found.

Mode of Distribution.

When the source of supply shall have been determined on, it becomes necessary to consider the system of distri-tion to be adopted. Formerly, in almost all English vns, this was effected by what is called the intermittent tem, in which the water was supplied from the mains ring a greater or less number of days in the week, and red in cisterns for domestic use in the intervals. This tem still prevails in London and in many other towns. late years, and principally by the influence and authority tly attached to the name of its most zealous advocate, Mr. wksley, beyond all dispute the ablest engineer practising peculiar branch of the profession connected with the tribution of water, a system known by the name of "the nstant, and high pressure," has been introduced. It con-ts in so arranging the supply, that not only the mains, but the house services, are always charged, day and night, l the pressure is usually such as to insure the delivery of ter at the highest level in a town at which it can possibly required.

Abstractedly considered, there can be no doubt but that, in ery point of view, the constant delivery must be the best. y person who would take the trouble to look at, for it is necessary to examine, the various receptacles (butts, ks, or cisterns) used to contain water, in the poorer rts of towns especially, cannot fail to be disgusted with foul contagion to which the water must be exposed. In

the houses of the rich, some precautions are taken to remove cisterns from the soot and filth of our town atmosphere, to place them beyond the immediate effects of the variations of temperature. But it is far otherwise with the houses of many of the middle, and of all the poorer classes; and in them, the recipients for the waters required for domestic use are almost always placed in positions where they cannot fail to become corrupt, and to imbibe principles highly injurious to the hygienic condition of the unfortunate beings condemned to use them.

In an economical point of view, the assertion of the advocates of the constant supply, that their system is preferable, seems also born out by facts, although Mr. Wicksteed used, formerly at least, to deny that it was cheaper. Evidently the cost of the cisterns themselves must be saved; and, as the draught upon the mains takes place during a greater portion of the day, and the momentary consumption, so to speak, must be less, the dimensions of the pipes may be diminished. It may be questioned, however, whether eventually there be any economy on the latter score; because it will be necessary to increase the strength of the pipes, and consequently their cost, in order to obviate the effects of the hydraulic jars produced by opening and closing the several house-services. From this cause, and from the necessity it superinduces of placing the house-services upon a series of subsidiary mains, called riders, it is possible that the cost of the pipes may be equal in both cases; but the economy resulting from the suppression of the private cisterns would not the less exist.

The suppression of private cisterns, it is true, renders it necessary either to form regulating reservoirs, or, if the water be pumped directly into the mains, to use machines able to supply the maximum demand. Such a general reservoir must, however, be far less expensive than several separate works of a similar character, even if of the same aggregate capacity. It also appears that it is far more advantageous to construct such reservoirs, than to establish machines of the

power required in the case of their omission, and to place these reservoirs at such heights as may maintain a constant pressure upon the pipes.

From observations made by Mr. Martin at Wolverhampton, it appears that the most copious consumption of water, in towns supplied by the constant system, takes place between the hours of 8 and 12 in the day, and again between 2 and 4 in the afternoon; the hours at which it attains its maximum limits are between 11 and 12, and 3 and 4, respectively. Between 8 and 12 about one-fourth of the total supply is usually consumed, and between 6 in the evening to 6 in the morning not more than one-fifth of the total supply is drawn off. From these indications it would appear that, theoretically, a service reservoir able to contain a minimum quantity of about one-fourth of the total supply, would suffice to regulate it in such a manner, that the machines should be able to maintain it by a constant equable effort divided over the ordinary working hours. In adopting some such arrangement, another advantage would be obtained; viz., that if the demand should increase, it would be possible to meet it, simply by making the engines work longer. If, on the contrary, it be found or thought advisable to pump into the mains, without the intervention of any regulating reservoir, the engines must be calculated so as to supply at all times the maximum draught upon the mains, which, according to the same authority, will be about one-twelfth of the total quantity between the hours of 11 and 12, and of 2 and . They would be forced to work all night; and, at the same original cost, would not be capable of extension.

The site to be chosen for the reservoirs must be, so far as economy of construction only is concerned, as near as possible to the source of supply, if the latter be situated at a low level; or to the commencement of the distribution, if the waters be led from a great distance. It is advisable, also, wherever it can conveniently be effected, that all such reservoirs be placed out of reach of the impurities of the at-

mosphere of all large centres of population; and that they be protected from dust and soot, as well as great changes of temperature. These considerations are often of so great importance, that they may cause it to be preferable to augment the engine-power, and construct the reservoir at a lower level, even if they do not lead to the abandonment of the latter altogether.

In addition to the remarks already made, with respect to the construction of reservoirs, in this and the preceding chapters, it is necessary to state, that whenever such works are to be executed for a town supply, they must be formed of such materials as are not likely to affect the qualities of the waters they are intended to receive. In all cases of this description, to a certain extent the waters must be stagnant; and they are then likely to absorb any soluble salts contained either in the earth or in the masonry of the wall. It appears, therefore, to be very doubtful whether water intended for town distribution should be stored in reservoirs which are puddle-lined or pitched with calcareous stones. Silicious sandstones, hard-burnt bricks, or the argillo-calcareous stones, bedded, where necessary, in powerfully hydraulic limes, or in cements, or iron, protected from the immediate chemical action of the water, are unquestionably the most advisable materials to be used in forming the faces immediately in contact with the water. The positions of the inlet and outlet pipes should be arranged in such a manner as to insure a constant flow through the body of water in the reservoir; and precautions should be taken to keep back any impurities which might be introduced, by either forming depositing-wells under the inlet-pipes, or by placing gratings or filters over the heads of the outlets.

The other accessories to reservoirs intended to hold waters for town distribution are simply—1, the valve-pit, placed at a small distance from the outlet through which both the pipes are made to pass if possible: it is formed for the purpose of working and examining the respective valves by means of

hich the water is admitted to or excluded from the reser-oir or the pipes, as the case may be; 2, the overflow-pipe, aste-weir, or other provision for regulating the height of the ater; 3, the scouring or cleansing-pits, with a discharge-pipe laced at such a point as to allow the whole of the water to e drawn off if requisite; and, 4, means of access to the ottom of the reservoir. It is desirable, and practically it is lmost always so arranged, that the outlet pipe be so placed, that certain depth of water should always be retained, excepting hen the cleansing pipe is opened. The object proposed by his arrangement is, to allow a more effectual deposition of he mechanical impurities of the water.

When the source of supply finally chosen is at a lower evel than the points from which the distribution is to be ffected, or than the highest point to which the water is to be elivered, it becomes necessary to employ some mechanical gent to raise it. For all town purposes, the choice of the articular agent is limited either to steam or water power, ccording to the circumstances of the town under considera-ion; and in both cases the motive power must be applied to umps, because they alone, of the various descriptions of ntermediate machinery, can force the water to the height and he distance it is generally required to overcome.

Evidently it must be preferable to adopt water-power, herever it exists to a sufficient extent, because it costs othing beyond the first outlay for the machinery and the rdinary repairs; whilst steam-power, on the other hand, equires a constant outlay for coals, and also a much more ontinuous and expensive attendance. But it rarely happens hat such a power is to be met with in the immediate neigh-bourhood of large towns; and in the majority of cases it is found that the streams giving the motive power are so ex-posed to interruptions in their flow, from ice, floods, or droughts, that they are seldom used in cases of this descrip-tion, in which regularity of action is a matter of such serious importance. The determining motives in the selection must,

them, depend upon the cost of the maintenance of st
power, and the interruptions the water-power may be expos
(supposing it to exist). If these interruptions should no
of any serious duration, they may be obviated by increa
the size of the reservoirs; but, of course, it would be ne
sary to make this consideration enter into the calcula
inasmuch as it may affect the final cost. The problem t
resolved in all similar cases is, to raise within a given t
the greatest quantity of water which may be required, at
least possible expense, not only for the moment, but eve
ally.

In estimating the power to be provided, it is necessary
take into account the weight to be raised; the height, or de
lift to be overcome; and the various causes of retardation
flow, arising either from the friction upon the sides of
pipes, or from any changes in their direction, whether i
horizontal or vertical direction. These last-named causes of
minished power will be discussed hereafter; but the diminu
may be, generally speaking, covered, by allowing for an e
dead lift of 12 feet per mile of the conducting pipes between
engine and the reservoir, unless any very extraordinary v
cal bends exist. For instance, let it be supposed that 1
gallons per minute are required to be raised to a
height of 120 feet above the lowest clacks of the pump
the water-line in the pump-well, and to be discharged
distance of $2\frac{1}{2}$ miles. Then, as a gallon weighs 10 lbs. a
dupois, in round numbers the calculation would bec
$10{,}000 \times (120 + 30) = 1{,}500{,}000$, moment of resistance. I
as a horse-power nominally is considered to be equal
33,000 lbs. raised 1 foot high per minute, theoretically
power should be $1{,}500{,}000 \div 33{,}000 = 45\cdot46$-horse po
But a steam-engine rarely works up to the nominal po
and a water-wheel falls short, even to a greater extent
that, in cases where the former is to be used, it beco
necessary to affect the theoretical result by the coeffic
0·85; and where the latter, by the coefficient 0·75, for

perfect description of water-wheel, and in the best work- ndition. It would be necessary, then, to provide a -engine of about 53·5-horse power, and a water-wheel out 60·7-horse power, to perform the duty above sup-

e towns of Philadelphia and Richmond, in the United s, and of Toulouse, in France, are supplied by water- ls, all undershot. Of these, the wheels at the Fair- t Water-works, Philadelphia, are the most remarkable, ccount of the volume of water they are designed to lift. is not less than about 10,000,000 gallons per day, with d-lift of 92 feet, through cast-iron pipes 16 inches dia- r. The engine house is built for eight wheels and ps; the former being 16 feet diameter, 15 feet on the and with a fall of 7½ feet, on the average, and making een revolutions per minute. At Richmond there were wheels 18 feet diameter, 10 feet on the face, with a 10 feet working two pumps, and raising 800,000 gallons per day reservoirs situated at a height of 160 feet above the water. At Toulouse, the wheels are 14 feet 5 inches dia- r, 5 feet on the face, with a fall of about 7 feet 6 inches; are two in number, and raise about 896,000 gallons per to a height of 67 feet above the water in the well.

he description of water-wheel to be employed must, of se, depend upon the conditions of the flow of water in river; it may be undershot, overshot, or breast, according e height of the fall, or the volume flowing through the es. Of the undershot wheels, those constructed upon celet's system, with curved floats, and working in a close entric channel, are the most economical, and yield the test effective power. With a fall of 5 feet, or under, produce a dynamical action equal to 0·75 of the theo- al power employed; with greater falls, this coefficient nds to 0·60; whilst undershot-wheels, with straight , rarely produce a dynamical effort equal to the latter, they are exposed to the serious inconvenience of being

pears advisable that these should be of sufficient capacity to allow the water to settle during at least three days. From thence it must be led upon the filter, without velocity or current, able to act upon the materials of which this may be composed. The filters themselves may be either chemical or mechanical; that is to say, they may either alter the qualities of the water, or they may merely act by removing impurities in suspension. To effect the former is necessarily a costly and difficult operation, and, indeed, so much so, that it may fairly be considered unattainable with the whole quantity required for a town supply. And if the water be immediately taken from a good mechanical filter, with as great rapidity as this can yield it, the quality will, in almost every case, satisfy not only the public demand, but also the real exigencies of the case.

Of the various descriptions of mechanical filters in use, the most important are those formed upon the principles adopted at Nottingham and Toulouse; upon the principles adopted by Mr. Thom at Paisley; upon those of the Chelsea Water-works; or finally, by the application of filtering-slabs, either natural or artificial.

The Nottingham and Toulouse filters consist of a series of tunnels, formed in the sand of the beds of the respective rivers from which the supply is taken. Wherever the materials of the bed are of a nature to allow this course to be adopted, it appears to be the most economical; but it is liable to the serious objection, that if the tunnels become choked in any way, their repairs are very difficult; and, as the efficiency of any filter depends upon the head of water over it, this class must evidently yield the least in the summer months, when the demand, on the contrary, is the greatest. It very frequently happens, also, that the construction of the tunnels gives vent to springs of very different qualities to those derived from the rivers; and it must always be observed, that the geological conditions which render the construction of such filtering tunnels possible do not occur in all cases;

t that, as a general rule, the beds of rivers, in large valleys least, are formed of a partially impermeable silt, or clay.

The Paisley filters are stated to be chemical as well as chanical in their action. They are formed by excavating ground to a depth of from 6 to 8 feet, and surrounding m with impermeable retaining walls and bottom. The or is divided into drains by means of fire-bricks placed on ge, and covered with flat tiles, perforated with numerous all holes, and supporting six distinct layers of gravel, reasing in fineness as they rise, which again are covered h very clean, sharp, fine sand, 2 feet thick, of which the per 6 inches are mixed with animal charcoal. Theoreti-ly, this would be the most perfect system of filtration; but is to be feared that the cost would be very great in the jority of cases.

The Chelsea filters consist chiefly of four beds of carefully aned gravel of variable thicknesses, but with an aggregate th of 3 feet, and increasing in fineness as they ascend, ich are eventually covered with a thickness of 3 feet of fine shed sand. The objection to this system of filtration, ich also applies to both those already described, is that they uire a large area, and therefore give rise to expensive thworks; especially as the depths to which they must be ried in order to obtain a head of water above, and the nels and pure water well below the filtering materials, st be considerable.

It is on account of the area and depth necessary for the er descriptions of filters, that the use of slabs becomes quently the most economical, inasmuch as they dispense h the necessity for so great a thickness of the filtering dium. The artificial filtering slabs made by Ransome Co. possess an advantage also in this, that the degree of osity may be regulated at will, and therefore the area may regulated precisely according to the degree of purification uired. Again, in this instance, as in so many others, the

precise course to be adopted must depend upon local considerations of economy or expediency.

In addition to what has been already said upon the subject of the flow of water in pipes, it is important to observe that the resistances to which it is exposed in practice are of a fourfold character; depending upon—1, the friction on the sides of the pipes; 2, the retardation caused by the bends; 3, that arising from the changes of direction from the mains to the submains or branches; and 4, the gurgitation which occurs at every junction.

The friction on the sides of the pipes depends upon their diameters and lengths, and the head upon the respective orifices; and, practically, this again is modified by a coefficient varying with the velocity of the water. Taking it into account, the quantity flowing through a pipe of uniform diameter, receiving its water from a reservoir at a high level, and discharging it constantly into another reservoir at a lower point, without any change of direction in the pipes, may be ascertained by the formula $Q = c\sqrt{\frac{H+\zeta-H'}{\lambda}D^5}$, in which Q = the quantity; ζ = the difference of level between the extreme orifices; λ = the length of the pipe; H = the head at the upper, and H' = the head at the lower, orifices respectively; D = the diameter; and c = a coefficient to be derived from the following table:—

Velocity per second	2 in.	4 in.	8 in.	12 in.	15 in.	20 in.	78 in.
$c=$	15·06	17·22	18·83	19·50	19·84	20·07	20·79

and for any length beyond $c = 21{\cdot}043$.

This formula, however, requires that the velocity should be previously known; should this not be the case, it may be ascertained as follows:—Call the sine of the inclination I, and make $K = \frac{H+\zeta-H'}{\lambda}$, in which the notation previously

served will be followed; then we should have, according to e Prony's formula, as given by Playfair,—

$$V = -\cdot1541131 + \sqrt{\cdot023751 + 32806\cdot6 \times \frac{D\,K}{4}}.$$

In practice, however, the conditions to be dealt with are ot so simple as those above supposed, and it becomes necesary to adopt other methods of calculating the resistance, hich may be explained as follows, nearly in the words of 'Aubuisson. When water flows from a pipe, the vertical eight of the surface of the fluid in the reservoir above the ischarging orifice is called the head, and is represented by in these observations. The velocity due to this head is, owever, diminished by the friction upon the sides of the ipe; so that the portion of the head acting upon the discharging orifice can only be represented by the height able o produce the velocity of the discharge. If this velocity be alled v, the height producing it will be $\frac{v^2}{2g}$; and $H - \frac{v^2}{2g}$ will be the portion of the head destroyed in creating it, and his portion, expressed in numbers, is known as the "loss of head."

As this loss of head is caused by the action of the sides of he pipes, it will be proportional to their length and their contour. In proportion, however, as the section increases, he resistance from friction on the sides will diminish, because t will be distributed over a greater number of molecules, and consequently will affect each one as well as the whole mass o a smaller extent; it will be, in fact, in the inverse ratio of he dimension of the section. The retardation will then be proportional to the square of the velocity with an addition of fraction of the simple velocity itself. It is to be observed that, in the course of these observations, the pipes are always supposed to be full; for if they were not, the flow f the water would be regulated simply by the laws affecting it in its course through open conduits.

Calling the length of the pipe L; S, the section; C, the contour; and a b, two constant coefficients; the expression of the resistance will be, $a \frac{C L}{S} (v^2 + b v)$, and we should have $H - \frac{v^2}{2g} = a \frac{C L}{S} (v^2 + b v)$. It is then only necessary to ascertain the values of the coefficients a b in order to apply the formula to ordinary purposes. Almost every author who has written upon this subject has attributed to them different values, so that great uncertainty still is attached to the correct solution of the problem. But it appears that the formula and values given in Weisbach's "Mechanics" are sufficiently accurate in practice, and they have therefore been adopted in preparing the Table No. 3. Weisbach calls the loss of head h_{1}, and confining his attention simply to the length and diameter of the pipe, he makes

$$h_1 = \left(0{\cdot}01482 + \frac{0{\cdot}017963}{\sqrt{v}}\right)\frac{l}{d} \cdot \frac{v^2}{2g} \text{ feet.}$$

It is true that Messrs. Provis and Peacock's experimental inquiries appear to indicate an important error even in this estimate of the values of the respective coefficients; but as the results obtained from their application are admitted to be always in excess, it would certainly be advisable to adhere to them in designing any works for the distribution of water through pipes; because any imperfection in the manner of laying, or a suddenly increased demand, might render necessary the supposed exaggeration of diameter they would lead to.

The table indicates the quantities discharged through pipes of the dimensions given, and the loss of head occasioned by its flow at the respective velocities in the margin; or, in other words, it shows the additional head required to maintain the supposed initial velocity calculated upon a foot lineal of the pipe. The discharge is calculated by the formula already quoted, $Q = S V$; and the initial velocity at the commencement of the pipe can at any time be ascertained by the formula

$= \sqrt{2\,g\,\text{H}}$; in which $g =$ the accelerating force of gravity $= 32\frac{1}{6}$ feet, and $\text{H} =$ the head over the point of discharge om the reservoir into the pipe, leaving out of account the ontraction of the fluid vein, which may at all times be comensated for by making the mouth of the pipe accord with the est form of conical ajutage.

The friction, and consequent loss of head, is considerably ncreased by the existence of any changes in the direction of he pipes, whether horizontally or vertically; and it is found o be in a certain definite proportion dependent upon the ratio f the width of the tube to the radius of curvature of its axis. Navier states that the loss may be represented by the fornula

$$h_1 = \frac{v^2}{2\,g}\left(0{\cdot}0039\,\frac{1}{r} + 0{\cdot}0186\right)\frac{a}{r},$$

n which $r =$ the radius of the curvature, and $a =$ the deveopment of the arc. According to him it would appear that h_1 is proportional to the square of the mean velocity, and to he length of the arc; it is a function of the radius, and ndependent of the diameter of the pipes; and that h_1 decreases in proportion as r increases.

It is usual to make r of the following dimensions when side mains branch off from a leading main:—

Diameter.	2 to 3 in.	3 to 4 in.	6 in.	8 in.	10 in. and upwards.
Radius...	1 ft. 6 in.	1 ft. 8 in.	2 ft. 6 in.	3 ft. 6 in.	5 feet.

It is also to be observed that in vertical bends the rate of delivery is also affected by the collection of air at the summit, and by the loss of any portion of the dynamical effort of the head required to overcome the resistance of the column of water to be lifted on the lower side of the bend. The former inconvenience is obviated by placing air vessels at the top of the upper limb; the latter, by accelerating the rate of flow before arriving at the bend. It is important, however, that, in all cases where pipes are laid with deviations from the

straight line, they be kept constantly full, so as to pre
as much as possible any accumulations of air.

The pipes from the pumping stations to the distribu
reservoir (and, generally, all pipes required for a town di
bution) should be laid about 4 feet below the surface,
carefully covered with earth and sand, or some non-condu
materials. The object of this precaution is, to protect
against the effects of frost, to maintain an equal temper
in the waters, and to place them beyond reach of injury
shock or jar by passing weights. In some portions o
distance between the two stations it may also be advisal
insert double lines of pipes, and to make occasional co
tions between the two, in order that, in case of repa
either of them, the flow may be maintained throug
other.

These remarks have necessarily been confined to th
sideration of the cases in which water is raised from a
level and pumped through pipes. If the source, ho
be situated at a distance, and at a higher level than the
mencement of the distribution, the course to be adopted
necessarily be modified. In such cases, if no very s
obstacles are to be met with, it is preferable that the
be led in a conduit rather than in a pipe; for evident
friction in the latter is much greater, and the height
point of arrival diminished in proportion. Such co
should be covered in all situations where the quality
water is likely to be affected, as in the neighbourhood o
towns, or during their passage through forests and under
or, again, in warm climates, where the temperature no
acts injuriously upon the quality, but also gives rise
evaporation of a very serious character. But if the co
be so covered, there must still be adopted precautions
suring a perfect ventilation and occasional renewal
air; and in the Roman aqueducts, wells also were for
occasional intervals, to allow of the deposition of any m
in suspension.

ɩdvantage of great importance attached to the use of s, rather than of pipes, for the conveyance of spring lies in this, that any of the earthy salts in solution they are likely to deposit in the course of time, are likely to produce injurious effects in open culverts as e in close pipes. The separation takes place, in air, ɩarlier period of the flow; and it must evidently be asy to cleanse or repair such conduits than it can be to ɩ the same operation upon pipes buried in the ground. other hand, it must be admitted that the construction of conduit is always a more expensive operation than the ment of pipes would be to ensure the discharge of the olume of water; so that, eventually, considerations omy may outweigh those derived from the theoretical ges above cited. As an illustration of the extent to the deposition of the earthy salts may interfere with ɩntract the effective area watercourse, the accom- ; sketch of the transverse of the conduit upon the ɩed aqueduct of the Pont d is added. The portion of a darker colour, round tercourse, represents the of calcareous matter which dually accumulated by pre- ɩn from the waters, although ɩains had previously been ɩ ensure their purity.

most serious difficulties which are likely to be encoun- ɩ the construction of conduits, are those arising from urrence of hills or deep valleys in the line they ought w. The former, if of considerable elevation, will re- ɩ be traversed in tunnel; the latter may be passed ɩy aqueducts, or by syphons descending from a reser- one side, and remounting to a second at a lower level,

on the other; the conduit recommences from the second reservoir.

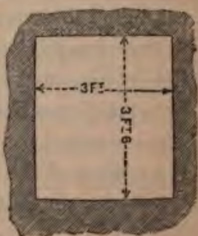
Amongst the relics of the Roman empire which have survived to our times may be found many very remarkable illustrations of both these manners of carrying across valleys the supplies of water intended for municipal distribution. As might naturally have been expected, however, in the defective state of the metallurgic arts amongst the ancients, the difficulties attached to the execution of large syphons led the Roman engineers to prefer the system of bridge aqueducts. Many of these are of such colossal dimensions, and such singular beauty, that it would be an injustice to mention them subsidiarily. The reader is therefore referred to the list of authors contained in the Appendix, should he desire to obtain further information upon this very interesting branch of the history of engineering. In modern times, the most remarkable works of this description are connected with the aqueducts constructed to convey to New York the Croton waters, or those executed for the supply of the town of Marseilles. Upon the former, in addition to a bridge aqueduct $1377\frac{1}{2}$ feet in length, with a maximum height of 150 feet above the foundations, there is a syphon aqueduct, with a depression of 102 feet in the deepest part, consisting actually of two cast-iron pipes 5 feet in diameter, with a provision for eventually placing two others of the same dimension. In the course of the latter, or the Marseilles Aqueduct, the total length of which is 98 miles, not less than $12\frac{7}{10}$ miles are in tunnel; and the valley of Roquefavour is traversed by a bridge 1312 feet long, with a maximum height of 282 feet.

The Turkish engineers introduced a system of interrupted syphons, if such an expression may be used, for the purpose of crossing long deep valleys, with the double object of saving the outlay necessary for the construction of masonry bridges, and of diminishing the chances of rupture in the earthenware pipes of which the syphons were formed. The name for this system is "souterazici;" and it consists of earthen pipes deriv-

ir supply from an upper reservoir, descending a hill nning along a valley, and then mounting perpendicu- to a second reservoir supported upon piers in masonry, ther lower level. From the second reservoir similar

ere conducted down the opposite side of the pier along ey, and successively into a third or a fourth reservoir at ly decreasing elevations, and so on to the other side of ey. Evidently this was a very rude method of meet- immediate difficulties of the case, and the loss of head e numerous bends must have been considerable; but as considerable ingenuity in the idea, and perhaps it d a better acquaintance with the laws of hydraulics are accustomed to attribute to the nation amongst he system arose.

dimensions and form to be given to the tunnels must ily be regulated, so far as the minimum is concerned, consideration that the workmen must be able to use ous tools, and to push to the extraction pits the mate- engaged during their operations. The nature of the aversed will also affect the sectional the excavation; for if it be of a o render lining indispensable upon s and top, as well as for the water itself, the dimensions evidently e increased. A miner can work lerable efficiency in a heading of represented in the margin; but be considered as the minimum in s, because the constrained position vorkmen prevents their employing the whole of their



useful power, and below this size they could hardly advanc themselves, without at all being able to work. It is also in portant that the workmen should be able at any time to vis and repair every portion of the tunnel. For these reason

Fig. No. 1.

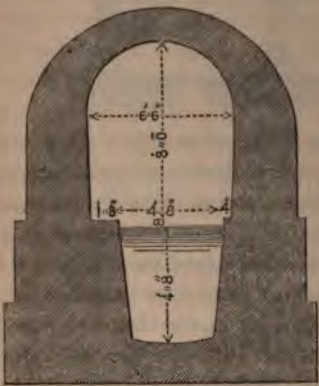


Fig. No. 2.

the conduit from which all the mains for the supply of Par draw the water is made of the dimensions indicated fig. No. 1 above. But it is also to be observed that this co duit, called the "Aqueduc de Ceinture," is about $1\frac{6}{10}$ mi in length, and has only a fall of 4 inches throughout, that the flow of the water only takes place in consequence the difference of level caused by the withdrawal of the wat through the various pipes branching from it. The section therefore much larger than it would be otherwise; and perha the desire to make it sufficient for the passage of a boat, haul by a man upon the species of towing path, may have led some exaggeration of its dimensions. Fig. No. 2 represe the section of the branch "Aqueduc St. Laurent" joining "Aqueduc de Ceinture," and supplying one of the quarters Paris.

Whatever be the dimension given to the tunnel, or to t watercourse of an aqueduct, directly it leaves the ground,

continued, as it were, in the open air, precautions must be ken to ensure the uniformity of the temperature. The ractice of the ancient Romans, which was also followed in he erection of the Croton Aqueduct of New York, was to keep he top of the aqueduct, whenever possible, at a distance of feet from the ground; and whenever it was necessary to carry it above that level, to cover the masonry with earth 2 feet 6 inches deep. It may, perhaps, be as well here to observe that, in spite of the criticisms of some late writers, the Croton Aqueduct is a very admirably executed work, and well worthy of study, if not always of imitation.

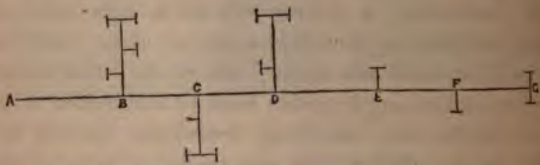
The formula which expresses the conditions of the flow of water in a pipe passing from one reservoir to another, ceases to be applicable when there is a series of side branches, or of sub-mains, deriving their supply from it. During the course of the distribution, a difference in the volume must necessarily arise from the fact that a portion of the water will be drawn off by these sub-mains; and in the latter portions of their course the supply mains must be diminished in dimension. But it may sometimes occur that the cost of new models for the smaller pipes may render it more economical to retain the original dimension; this question of detail will therefore require to enter into the comparative estimates of the various modes of effecting the supply. It is, however, necessary, before deciding the dimension of any main pipe, to take into account the probability of an eventual increase in the demand upon it.

Mr. Hawksley states that the method he adopts to ascertain the diameter to be given to the pipes upon the constant system, is to divide the length of the main in a street into portions of 200 yards each, and assign to every such portion the quantity it would be likely to require, supposing it to be discharged in four hours. He allows a loss of head of 4 feet for every 200 yards, and adopts the formula $\frac{1}{15}\sqrt[5]{\frac{q^2 l}{h}} = d$,

in which $q =$ the number of gallons.
$l =$ the length of the main, in yards.
$h =$ the head, in feet.
$d =$ the diameter, in inches.

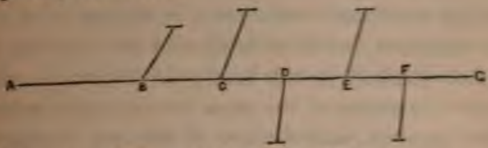
The course recommended by Claudel, in his "Formules l'Usage de l'Ingénieur," is perhaps more accurate, althou more tedious; it may be described as follows, nearly in h own words:—

Let it be proposed to supply a district by means of a pi of uniform diameter throughout its length, and discharging th water by means of pipes constantly flowing. Then the di meter of the pipe should be sufficient to ensure the delive of the water from each opening at a slight distance above th point of discharge itself. This diameter is assumed; and th



loss of head for the distance between A and B is calculate from the table; and, the loss being deducted from the initi head, will give that acting effectively at B, which must be suf ficient to ensure the delivery of the water at the orifices upo the branch from B. The loss of head between B and C is as certained in a similar manner, it being observed that th quantity discharged by the main will be diminished by the quantity withdrawn at B. As before, the head thus existing at C must be sufficient to ensure the delivery of the water required to supply the orifices placed upon that branch. Pro- ceeding in this manner with the remaining branches, it will be seen whether the head existing at the last will be sufficient for its supply. If not, it will be necessary to try a larger diameter; if it be too great, a smaller diameter must be adopted.

t now be required to determine the diameter of a pipe ng water from both ends, and supplying in its course orifices requiring definite quantities. In such a case happen that some of the orifices are supplied entirely ; some entirely from B ; whilst some, as D, for instance, erive their supply partially from one, or from the other ; may be, from both.



he diameter of the main in either of the parts D A, D G, must such, that if D be supplied from both, the head at D and consequent entry from both sides should be equal. It is essary to proceed as in the last case, in order to ascertain t this is the case, and to assign some diameter to both A l G, and after deducting the losses of head occasioned by several branches, B C E F, the remaining effective heads on the respective portions of the main at D will be deter- ined. Should they not be equal, one, or both, must be tered as the results obtained may indicate.

Should the supply main derive its waters from two pipes hose delivery is known, and should it be desired to deter-

ine the diameter of the pipe A B, so as to ensure a particular tribution upon its length, the course to be followed would as follows. A certain diameter is assigned to A B, and as discharge is known, and the difference of level between A l B is also supposed to be known, the effective head requi- to ensure the fulfilment of the required conditions is easily ertained. If, then, the diameters of A and B be also supposed, the volume to be supplied by them is known, it is easy to

calculate the loss of head upon each of them, which, being deducted from the initial heads at C and D, will give the net effectual head remaining at A. This head should be the same for both pipes, and equal to that required to secure the delivery already supposed to take place between A and B; and if the respective diameters should not be such as to ensure these conditions, they must be modified.

When the distribution takes place by means of a conduit of different diameters, it will be found that the system indicated in the first illustration will satisfy the required conditions, because the diameters of the pipes are constant between two successive openings, and the rate of delivery is also uniform between them. It is necessary, however, in calculating the loss of head, to allow for the difference in the diameter of the pipes.

In carrying out the working details of any town distribution of water, there are numerous precautions to be taken to ensure that the pipes should be protected from the jar of carriages and from the contamination of gas pipes *. A minimum depth of 4 feet from the surface will suffice for the former; and in order to guard against the latter, it is customary to place the water pipes at a lower level than those conveying the gas. Care is also required to be taken to avoid what are technically

* It is usually considered that the temperature of the water is affected by the depth at which the pipes may be laid from the surface, on account of their being to a greater or less extent removed from atmospheric influences. But from the experiments made by M. Girard (see "Mémoire sur la Pose des Conduites d'Eau dans la Ville de Paris, 1831"), it appears that at whatever temperature the water may enter a pipe, if it flow continuously, it will leave it at precisely the same temperature. The experiments were very carefully made, but they require confirmation.

The same authority states, that the dilatation of cast-iron pipes was 0·00000300228 of a foot for every degree Fahrenheit, if free and in the open air; when the pipes were filled with water, and buried in the ground, the dilatation was considerably reduced. The pipe itself assumed a temperature which was a function of the difference of temperature between the surrounding media, and was nearer to that of the denser medium.

called "dead ends," or portions of the mains in which there exists no current, and in which necessarily the water must become stagnant. It is necessary, also, to make every sub-main, and, if possible, every house-service, independent of the other portions of the distribution, so that in case repairs are required of a nature to render it necessary to shut off the water, the privation may affect as few houses as possible. Sluices, or, as they are sometimes called, "hydrants," are placed close to the embranchments upon the mains; and it is advisable to place a small stop-cock at the junctions of the house-services.

Fire-plugs are placed in London at distances varying in the districts of each separate company, but it appears that, upon the average, there is a fire-plug to every ten houses. In large towns, also, it is advisable to place stand pipes at distances of about 500 yards, for the supply of water-carts. This branch of the public service is found to require a supply of about $1\frac{1}{4}$ pint per yard superficial for every time it is performed; and in our climate it appears that it is required for 135 days in the year, and in summer it will frequently be necessary to water the roads twice a day.

CHAPTER VI.

MARINE ENGINEERING.

THE phenomena which modify the action of large bodies of water upon works erected in them, or upon bodies floating upon them, and which it is therefore necessary to take into account where these are considered, may be grouped under the principal heads of the winds, waves, tides, and currents. The action and reaction of headlands, the effects of the outline of any particular sea-shore, the quantity of alluvial matter brought down by any rivers, the volume of the latter, and an infinite number of other modifying causes, also require attention. Within the limits of this treatise it will be impossible to enter into their examination in sufficient detail; but where-

ever it is possible to treat them incidentally, it has ent into the plan of the work to sketch at least their general l ings upon the practical operations of the engineer.

The Winds.

As is universally known, the wind blows over the e in every possible direction, with every imaginable var of intensity and duration, in the temperate zones; under the tropics it varies at definite intervals of time, well as prevails in constant directions. In all countr however, notwithstanding the apparent irregularities, th are *prevailing* winds easily to be ascertained; and, genera speaking, those winds produce the most frequent tempests the localities where they blow.

The velocity and strength of the wind vary within a v wide range, and it is usually considered that they may represented as in the following table, supposing the eff produced to increase as the square of the velocity.

Name of wind.	Velocity per second.		Effort per yard squar
	ft.	in.	lbs.
Light breeze, hardly perceptible . . .	1	8	0·0498
Gentle breeze	3	4	0·1975
Light wind	6	8	0·7913
Rather strong wind, best for sailing . .	18	0	6·0699
Strong wind	33	0	20·0669
Very strong wind	66	0	80·2676
Tempest, or storm	70	0	101·6279
Great storm	90	0	146·3443
Hurricane	118	0	260·0567
Hurricane able to tear up trees, &c. . .	150	0	406·5118

The effort being supposed to be exercised in the directi of the wind, and upon a surface, normal to it, of one ya superficial area.

It has been also remarked, that in level countries the wi blows downwards, forming an angle of about 18° 20′ with t line of the horizon.

In consequence of this general direction and its veloci *the wind*, by its action upon the superficial layers of a lar

y of water, can accelerate or retard their movement, ac-ling as its direction coincides or not with that in which se layers may be flowing; and it will develop upon them, lso upon still waters, a series of elevations or depressions. ese variations of level are called *waves;* and they are the eater in proportion to the surface upon which they are oduced, and the length of time the wind may have blown the same direction and with the same force. The agita-on will be increased if the wind should blow in a direction pposite to that of the current of the water; or if it should uddenly change its direction; or, lastly, if land winds meet aves generated at a considerable distance by other winds lowing in shore. This last meteorological condition recurs ith sufficient frequency to have attracted the attention of ailors, and gives rise to one of the most dangerous forms of gitation to which the sea is exposed.

Some idea of the effect of the wind upon still waters may e formed from a fact mentioned by Franklin, viz., that in a ond 9 miles wide, with an average depth of 3 feet, a strong ind drove all the water from one side, which was laid bare, hilst on the other the water was increased 3 feet in depth, ing 6 feet deep instead of 3 feet, as in the ordinary state.

Upon the sea-shore, and occasionally at great distances land, the wind, by its action upon small incoherent mate-als, can frequently cause them to assume a progressive otion in its direction. Instances of this are to be found the dunes of the Bay of Biscay, and the sands of the great serts.

Waves *.

Waves, or undulations, are the alternate elevations and pressions in a vertical direction, which for all ordinary rposes may be assumed to be caused by the action of e wind alone, leaving out of account the very rare hurri-ne and earthquake waves which occur in some particular

* See Brémontier, Emy, Sganzin, Minard, &c.

districts. They are sometimes subdivided into waves breakers; the former term being applied to the long un tions met with in deep water and in the open sea, or upon sea-shore in still weather; whilst *breakers* are the vi waves caused by storms driving the water with violence reefs of rocks or upon precipitous shores. Colonel Em addition to the above terms, uses also those of *long run waves*, or those possessing a movement of translation, usually caused by the wind blowing from the sea inland; of *chopping waves;* these are, in fact, only modifications of running waves, from which they differ in this, that they not appear to have any movement of translation.

Waves of different dimensions may often be observed vancing simultaneously in every direction, crossing one ano at almost every angle, and presenting occasionally the app ance of great disorder. If, however, they be examined at tively, even during the most violent agitation, it may be ceived that each wave forms part of a system of undulati proceeding from some definite source of disturbance, and this undulation could subsist in perfect independence of the rest. The combination of such systems forms a mult undulation; and it may be observed that a periodical incr of elevation takes place in the waves, which is attributabl such a combination of two systems of undulation; the composed of the waves which are the most apparent, other of those possessing greater extent, but less vert height. Waves coming in from the open sea are, howe so much more powerful than the cross waves, that it is rarely that we need consider them otherwise than as sin uncompounded waves.

Those portions of an undulation situated above a h zontal line passing over the normal plane of the water, called its *crown*. The depressions separating the crown consecutive waves are called the *troughs*, and they are be the horizontal line above mentioned. The *length* of a wav usually understood to mean the distance between the axes

o consecutive troughs; the *height* is ascertained from the rpendicular distance between the bottom of the trough and e top of the crown.

The apparent motion of waves is one of translation; but if he real motion of the molecules of the surface be closely bserved, it will be found that they merely oscillate in vertical plane, without advancing in a horizontal direction. The movement of translation, then, only affects the form of the wave, but it in no wise modifies the position of the molecules; somewhat in a similar manner to the effect roduced in a field of standing corn, where the waves caused y the wind appear to recede, but at the same time the talks themselves are fixed. Or perhaps the apparent movement of waves may be more strikingly illustrated by the tation of a screw upon its axis between two fixed points. he immobility of a floating body in the horizontal direction , however, the most decidedly marked in the portions of the ave situated about the middle of the rising and falling des.

Waves do not modify the natural current of the water pon which they are formed; so that a body floating upon e surface of a current will follow its direction, notwithstanding any superficial undulation. On the other hand, the current carries forward the waves existing upon it without in any ay interfering with the mechanism of their movement of scillation. Thus, calling the velocity of the waves that which they would possess in still water, their apparent velocity upon a current would be either the sum or the difference of their own velocity and that of the current, according as hey move in the same or in opposite directions thereto. Colonel Emy, however, states that sometimes at the mouths of rivers the velocity of the waves rolling in from the open sea, is sensibly equal to that of the river current. Under these circumstances the waves form, as it were, fixed rolls or ridges, to which the current of the river is forced to adapt itself.

Waves produced by the wind, or by any other cause, may become superposed upon others, arising from similar causes, but at an earlier period. Like the undulations of sound or of light, they are known to cross one another in every direction without being affected in a manner able to destroy their respective velocities. But Brémontier observes that two systems of undulations may coincide at intervals of greater or less duration, and thus give rise to waves of greater elevation than those which either precede or follow them. The directions of liquid waves may, nevertheless, be inflected or reflected in precisely the same manner as those of light or of sound, and the waves so diverted from their original direction are known under the name of *reflected waves.*

Although it is well known that waves do not arrive upon the shore with either the same volume or the same force they possess in the open sea, they still retain a form and a velocity which, for all practical purposes, may be considered constant, so long as their cause subsists. But, again, although this may be considered to hold good for a comparatively short period of time, it must be borne in mind that the form and velocity are in fact very variable, depending upon the wind and the time it may have blown in one direction, even if we do not take into account the numerous local causes contributing to modify the action of the waves.

There are several theories to account for the formation of waves, which may be found in the works of Newton, Laplace, La Grange, Poisson, Biot, Brémontier, Emy, Virla, Young, Scott Russell, the "Philosophical Transactions," the "Transactions of the British Association," "Les Annales des Ponts et Chaussées," &c. For practical purposes it may, however, be sufficient to state, nearly in the words of M. Reibel, that the majority of engineers adhere to the hypothesis propounded by Newton, which accounts for the undulatory movement of water, by supposing that the vertical depression of the liquid molecules by any external agent, is transformed at the lower limit of the agitation of the sea into a

orizontal movement of communication, similar to that which ccurs when the waters in one branch of a syphon are epressed. And it is to be observed that, when waves are roduced by a cause acting instantaneously, as in the case of heavy body falling, they are transmitted in concentric circuar rings, firstly of feeble elevation, but subsequently increasng, and the oscillation in the various rings is isochronous. he equality of the surfaces of the hollow, and the increase f volume of the wave, and the incompressibility of water, ppear to confirm this theory, which is, however, combated y several eminent engineers, amongst others by Colonel my, and after him by Mr. Scott Russell.

According to those authorities, the molecules of water in aves are affected by a series of orbicular movements, either mple or compound, whose intersections form the surfaces of e waves themselves. This theory explains in a very plauible manner many of the phenomena of waves; but it is far om being generally adopted, especially in the case in which is applied to the explanation of simultaneous multiple unlations crossing one another.

It was long believed that the agitation of the sea did not escend to a depth exceeding from 16 feet to 17 feet 6 inches om the surface, and, so far as the waters of the Mediterraean only are concerned, this law is still believed to exist. rémontier has, however, shown that in storms the agitation escends much below this depth, and he asserts that upon he banks of Newfoundland it even extends to the enormous epth of 530 feet from the surface. To the south of the ape of Good Hope, breakers have been observed above ocks situated 660 feet below the still-water level; and cent observations in the Channel have shown that, although e agitation diminishes with the depth of the water, it scends far below the supposed limit of 17 feet. But it ust be evident that the degree of violence of the agitation the surface must considerably affect the depth to which its ects may extend.

The usual height of waves varies in different seas; tl in the Channel, when they develop themselves freely, t measure about from 13 feet to 16 feet 6 inches from the l to the crown; in the Bay of Biscay, from 19 feet 8 inche 23 feet; in the Mediterranean, from 9 feet 10 inches 13 feet 2 inches; and in the Lake of Geneva, they meas about 8 feet 6 inches. Immediately opposite Southamp the waves attain 7 feet in height, and in some of the widest water reaches of the Seine, close to Paris, the waves occasionally as much as 2 feet 6 inches from the base to crown. According to Brémontier, ordinary waves have length equal to four times their height.

From the effect of the pressure of the wind upon sides of waves during storms, they assume frequently inclined position. The percussion of such waves upon shelving shore must be much greater than that of wa whose axes are vertical; because, independently of tl inclination, they are usually animated by a very consider velocity. Should the wind suddenly acquire a great intens and its direction (which, as before stated, is slightly incli to the horizon) coincide in plane nearly with that of waves, whether it be in the same direction, or in an oppo one, the surface of the sea will be covered with small break on every side.

M. Virla infers from his observations at Cherbourg, the duration of an oscillation augments with the lengtl the waves, and the depth below the surface to which the o lation extends. The velocity augments with the length, diminishes with the depth of the agitation; whilst both tl expressions are independent of the height of the undulat It would thence appear that, in waves whose height is sm and which are of great length, the agitation might descen rocks placed at a great distance from the surface. And also to be observed that, if the undulation of the sea m any reef or rock, either vertical or inclined to the hori above the point where the agitation ceases, or if the

iore occur near the bottom of their visible depres-, a series of variable effects are produced, which depend cipally for their mode of action upon the direction of shore with respect to the prevailing wind of the particu-locality.

There are some anomalous effects produced by the percus-n of waves, which are of great importance in their bearing on the form of hydraulic works. Thus Brémontier men-ns that the existence of submerged rocks, at from 30 to 40 t below the surface, augments the height of waves occasion-ly as much as from 7 to 10 feet, whilst, under other circum-nces, breakers will not be formed upon rocks only 20 feet low the water. Again, it is known that if the entrance to large basin be narrowed by means of bodies floating in such manner as to be about from 8 inches to a foot above and low the water-line respectively, the sea in the passage ill become much more agitated when the waves arrive rpendicularly to the narrowed channel. The explanation f this phenomenon appears to lie in the interference which kes place between the direct waves and those reflected from e sides of the entrance, and the effect of this interference ill be either to increase or diminish the extent of the undu-ation, according as the directions of the two waves coincide r not; but it only modifies the height, without producing ny effect upon the length of the waves. Possibly it may be n this manner that we may explain the fact that the waves of the Mediterranean, which are so much shorter than those of the Atlantic, are often quite as lofty; for the reflection of the waves from the shore may be sufficiently powerful to ffect their height, whilst the surface is not of sufficient idth to allow of the formation of very long waves. Should he narrowing of the channel produce any serious interference ith the length of the waves, they will break, and produce a ery agitated and chopping sea. The same effect is also to be served when the bottom or the shore is covered by a series

of rocks projecting above the line at which the superficial agitation ceases to be felt.

When a reflected and shortened wave, such as those just mentioned, meets a large wave coming in from the open sea a violent reaction takes place, a little to the seaward of the obstacle giving rise to the interference. This is called the *ground-swell*, the "ressac" of French engineers; and it is observed that it ceases to be felt at a distance of about half a mile from the obstacle, and to be the most powerful in narrow lakes bounded by abrupt sides. Moreover, the effect of abrupt vertical obstacles to the further progress of waves, when they are partially immersed and partially above the water-line, is, to increase the height of the waves by the reflection produced by the immersed portion. At the same time, should any part of the wave rise above the upper edge of the obstacle, it will continue its original forward motion, but with considerably augmented velocity.

If the waves, instead of meeting a vertical obstacle, strike upon a gently inclined surface, about the depth of the agitation, the horizontal transmission of the pressures will be modified. It has been demonstrated, theoretically and practically, that the ascensional force of the water will be increased; that the summits of the waves flowing over the inclined shore will rise to a higher point than they would do if the shore were abrupt; and that this excess of height would increase from one wave to another, until the last one will present a nearly vertical side to the shore at the moment of its breaking. The return wave meeting the next incoming one, renders the outline of the latter still more precipitous towards the shore at least.

Brémontier was led to believe, by the results of some experiments, that the maximum height attained by breakers corresponded with a plane inclined at an angle of $22\frac{1}{2}°$ with the horizontal line; but Reibel is far from admitting that this result is to be received implicitly. All that is absolutely

upon the subject is, that the excess of the ascensional t of the waves upon an inclined surface, increases in me proportion as the rate of inclination with the hori- l line (at which it is zero) up to an angle, hitherto ermined, corresponding to the maximum; and that e the increase of height gradually returns to zero, oportion as the plane approaches the vertical line, leaving f the account, in this latter case, the effect produced by eflection of the waves. On many natural beaches, and in aulic works, the slope of the shore terminates in the r part in an abrupt face, either with or without any fill- in of the angle. An accumulation of all the above effects follow from such a form, and vary in every particular , according to the combined action of the tides, winds, currents upon the waves. When these are driven into rnal angles, either of the shore or of the works, and are e again reflected, they attain an additional height. Some hors also suppose, that the elasticity of the air drawn ler the crest of the wave, may add to the reaction produced ependently by the solid obstacles.

When a separation is placed in a basin of any area perpen- ularly to the direction in which the waves advance, the er portion, in the immediate vicinity of the separation, l be more agitated than before, on account of the inter- ence with their propagation, whilst the second portion hind the separation will be rendered calmer. This effect uld take place, even if the obstacle were capable of being bmerged; but it would be far more perceptible if the sepa- ion should be surmounted by a wall, or some other means which the action of the wind upon the interior portion the basin might be obviated. Should the separation, instead being continuous, consist of a series of open spaces, each ace would become the center of new undulations in the cond portion of the basin; but they would diminish in ight with a rapidity the greater in proportion as the open- gs were less, compared to the dimensions of the zone of

water behind them. In such cases, however, the agitati the sea is much increased within the spaces themselves. is upon this principle that piers or breakwaters forme open stockades, or of piles, produce still water upon sheltered sides, when they are placed transversely to direction of the waves, as in the case of Yarmouth, Haven near Edinburgh, Ostend, and Cronstadt.

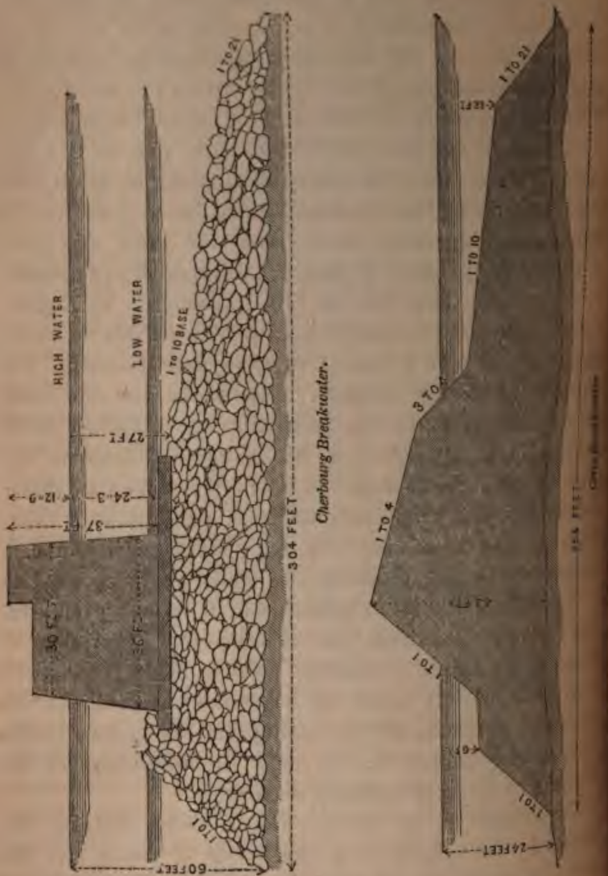
If a species of channel be continued beyond the supp openings in the separation, whose direction corresponds that of the principal waves, and whose width is nearly to that of the opening, the waves from the outside w continue their original course up this channel, unti friction had destroyed their progressive motion. The rap with which this effect is produced depends upon the sha the channel, and would be the least if it were continuous insubmersible for the whole of its length. A series of spreading out from the sides of the channel, and prese shelving shores, would accelerate the destruction of the w It is upon the various principles involved in these supp illustrations that the construction of jetties, whether or open, have been based; and they have been adopted a long series of practical observations, confirming the theor deductions of such authorities as Brémontier, Sganzin, ford, and the very distinguished engineers of southern I

The destructive action of waves upon the sea-shore m easily understood, if we consider the mass of water set in motion, and the velocity they frequently impart this has on some occasions been ascertained to be ev much as 70 feet per second. Messrs. Virla and Minar some interesting facts observed at Cherbourg and Al which appear to prove that the limit of the power of municating lateral motion in the greatest tempests, is n equivalent to an effort of 7865 lbs. per yard superficial. Stevenson states that, from experiments made on the coast of Scotland, in positions exposed to the whole fury o Atlantic, it appears that the average pressure of the

ng the summer months was equal to 611 lbs. per square ; whilst in the winter it was 2086 lbs., or three times as t. During the storm of the 9th of March, 1845, it was 3 lbs.; and on the 20th of November, 1827, the spray rose feet above the mean level of the water at the Bell Rock hthouse, so that Mr. Stevenson calculated the pressure of waves to have been equal to about 3 tons to a square foot. the western shore of Ireland, Lord Adair has measured ing breakers not less than 150 feet high; and Sir C. Lyell tions, to illustrate the transporting power of waves, that the shores of the Shetland Islands, in the year 1818, a k, containing rather more than 325 cubic feet, and hing probably about 23 tons, was transported to a distance 0 feet, and there broken into fragments. At Algiers, ks of concrete of about 354 cubic feet in volume, and a ific gravity of 2·2, were torn from their positions, and ed a considerable distance. One of the concrete cones e by De Cessart for the breakwater of Cherbourg, which ained about 445 cubic feet, has, however, resisted all the ns of the Atlantic since the year 1808. We may there- assume, with tolerable confidence, that a mass of about cubic feet in volume, with the specific gravity of con- e, would be the minimum size which could be exposed he action of the ocean without fear of its being removed. these remarks must not be considered other than as cating approximative results; because, in the calculations which they are based, no allowance was made for the inution of specific gravity arising from the various bodies g entirely immersed, nor were the conditions of the ion upon the beds carefully ascertained.

he inequalities of the slope of a shore diminish the ement, the velocity, and the height of waves, and the imum of the intensity of their action is usually found orrespond with the level of the half tide, or the mean ht of the sea; but there appear to exist some anomalies respect to the last law. Thus, at Cherbourg, the rough

slope at the foot of the breakwater was found to diminish the violence of the waves, and the maximum effort took place at the level of half tide, or between 10 and 13½ feet from



Cherbourg Breakwater.

the top of the wall. But at Cette, the maximum effect took place at 5 feet below low tides, upon the breakwater itself, whilst upon the seaboard the line of action lowered to

21 feet below low water, and on the inland side to 15 feet from the same level. A sketch of the transsection of the Plymouth Breakwater is added in this

Plymouth Breakwater.

in order that it may be compared at once with some other most important works of the same description to executed.

*Tides**.

action of the tides upon a sea-shore, or upon any works d within their range, is a source of great destruction. arise from the periodical elevations and depressions of a, caused by the combined attractions of the sun and oon, and they are the most perceptible in the largest of water. In the Pacific they are greater than in the ic; in the latter, again, they are far greater than in editerranean; whilst they are almost imperceptible in r seas, such as the Black Sea or the Caspian.

waters of the sea rise and fall twice in each consecuterval comprised between the returns of the moon to per meridian. The mean interval of these returns is 5 day, so that the mean interval between two succesgh tides is 0·517525 day; the mean time of the low tide g this interval again into two nearly equal portions. the case of all quantities susceptible of a maximum minimum, the increase or diminution of the tides tosuch limits is proportional to the squares of the time d between the high and the low tides.

rising tide is known by the special name of *the flood;* ling tide, by that of *the ebb.*

* See Newton, Laplace, Whewell, Airy, Lubbock, Mounier, &c.

The height of the full tide varies every day, and the rate of variation depends upon the phases of the moon. The rise is greatest at the syzigies, when the moon is either in conjunction or in opposition; it is least at the quadratures. In the former case, the attractions of both the sun and moon combine to raise the water; in the latter, they mutually counteract one another. But it is to be observed, that the period of the highest tide at any place upon the eastern shore of a continent does not correspond exactly with the syzigies, for Laplace and Whewell have observed, that the highest tides at Brest followed the syzigies at an interval of 36 hours, and those of London at an interval of $2\frac{1}{2}$ days from the same period. So that if the tide were high at the moment of the syzigy, the third tide following it at Brest, and the fifth at London, would be the highest. The difference between the epochs of highest tides at various points, appears to be owing to the time required for the westerly passage of the great tidal wave from the ocean.

The height to which the sea rises at high tide is exactly proportional to its fall at low tide; but there is an irregularity between the two tides of the same day. The *total tide* is therefore ascertained by taking the sum of the heights of the two sides above the intermediate low tide, and dividing it by two. At Brest, where observations have been carried on for the longest period, the total tide at the syzigies is stated to be 15 feet 10 inches, and in the quadratures it is but half that quantity.

The tides occurring at the syzigies are called the *spring tides;* those occurring at the quadratures are called the *neaps*. The former are much increased when the moon is in perigee. An augmentation also takes place at the time when the sun's declination is zero, or at the equinoxes; and the greatest tide occurs when a new or full moon happens near the equinox whilst the moon is in perigee, and her action is still further increased if her node coincide with the perigee. There are other variations in the heights of the

s, arising from the movements of the sun and the
on, which are continually making the circuit of the
vens at different distances from the plane of the equator,
account of the obliquity of the ecliptic and the inclination
the lunar orbit. These combined motions cause great
gularities in the tides, so that both the time and the pre-
height of the high water are perpetually changing.

Laplace observes, that the height of the tides depends also
y much upon local circumstances. Thus the tidal undu-
on confined within a narrow strait may become consider-
y increased, and the reflection from the opposite shore
y also augment it to a great extent, especially in the
ernal angles of the same coast; and it is on this account
t the rise of the tide, which is so small on the shores of
islands in the Great Southern Ocean, becomes so great in
ports upon the eastern shores of the Atlantic. High
nds, and especially the equinoctial gales coinciding with
spring tides, may also give rise to great irregularities in
ir heights.

The Governments of most civilized nations publish an
nanac of the normal heights of the spring tides at the
st important positions upon their shores, which heights are
luced from astronomical observations. It is usual to
ompany these tables with a column of numbers called the
fficients of the other minor ports, by means of which it is
y to find the height of the tide in any one of the latter,
multiplying the unity of the tide by the coefficient
igned to that particular port. The unity is to be ascer-
ned on the days immediately after the syzigies of the
uinox.

What is called the *vulgar establishment* of a port is the time
psing between the hour of the full moon at the syzigy
d the high tide occasioned by it; and the astronomical
bles contain a series of the establishments of the principal
rts of Europe. The corrected establishment is the lunar
ur of high water freed from the semi-menstrual irregularity,

for the interval of the tide from the moon's transit is affected by a considerable inequality, which goes through its period twice in a month, depending on the moon's distance from the sun in right ascension, or on the solar time of the moon's transit. A simple, but not very exact, way of ascertaining the hour of high tide consists in adding to the hour of the vulgar establishment of a port as many times 48 seconds as there have elapsed days from the full or new moon. It is, however, to be observed that, although the astronomical reasoning with respect to the tides has been demonstrated to be correct beyond all possibility of doubt, yet there are local and occasional irregularities which modify the results of the tidal movements to a great extent. For instance, storms blowing from the sea have sometimes such power, that the tides of the quadratures are raised up by them to heights exceeding those of the syzigies.

Smeaton mentions that, at the port of Christchurch, in Hampshire, the neap tides rise as high as the spring tides when the wind is blowing hard from the west; and the same phenomenon has been observed at Dunkirk. But the memorable storm of Nov. 23, 1824, occurred at the syzigies, for the new moon had taken place on the 20th. The tide, on this occasion, rose at Plymouth nearly 8 feet 6 inches above its usual height at spring tides; the calculated coefficient for the day having been 0·89, whilst the coefficient for the tide which did occur was 1·13. In regard to hydraulic engineering, however, the coefficient to be derived from these extraordinary tides is of little use as a means of ascertaining the height to which marine works may be affected, because the same wind which causes them to rise beyond their usual level at the flood, causes them also to fall to a correspondingly lower level at the ebb; whilst the coefficient only refers to the difference between the tides, without furnishing any definite indication as to the height to which the flood may rise. In the present state of our knowledge there are, in fact, no means of predicating with certainty the possible

ıfluence of the wind upon the rise of the tides. In seas, ıch as the Mediterranean, where these are but feeble, the inds have a greater disturbing power, however, than in the cean; and it has been observed that the tides upon the outhern coast of France, which are usually from 6 inches o 1 foot, are sometimes carried by storms, at very irregular ntervals, to a height of 3 feet 6 inches.

On account of the configuration of the land, the tides, as was before observed, rise much higher on the shores than hey do in the open sea, where they are only affected by the ttractions of the sun and the moon. The most remarkable ariations known are considered to take place at Chepstow, here the rise of spring tides is about 60 feet; at Bristol it s 40 feet; in Mount St. Michael's Bay, it is 46 feet; in the Bay of Fundy and on the coast of Nova Scotia it is about 0 feet; whilst in the Northern Atlantic it is on the average rom 10 to 12 feet; at St. Helena, only 3 feet; and on the hores of the islands of the Pacific it is barely perceptible.

The propagation of the tide in rivers partakes of the movement of waves or breakers upon an inclined shore. They ise to a higher point, and continue to a later period, in the nterior of a country than they do at the mouth; but the eight to which they rise depends greatly upon the outline f the banks of the river; and it appears that the strength nd direction of the wind has a greater influence upon the ides of rivers than it has upon those of the sea-shore. In he Elbe, at Hamburg, for instance, with a strong north-east wind the height of the spring tides may be doubled or even rebled.

Theoretically, the time employed by the sea to rise through he different portions of the tide will be represented by the ength of the arcs of the circumference of a circle, whose ertical diameter should be the total rise; the arcs being omprised between horizontal lines drawn from the extreme oints and corresponding points upon the vertical line, so hat the half circumference will represent the total time

between high and low water. The disturbing causes immediate vicinity of the sea-shore are, however, merous, that it is necessary to make particular observati every locality where it may be required to construct exposed to the influence of the tides.

Thus, at Rochefort, near the mouth of the Charente, a double high tide is formed for about three days in each quadrature, somewhat in the manner represented in the sketch in the margin, in which the abscissæ represent the times between the variations, and the ordinates the heights*. In the Orwell, on the Essex coast, as

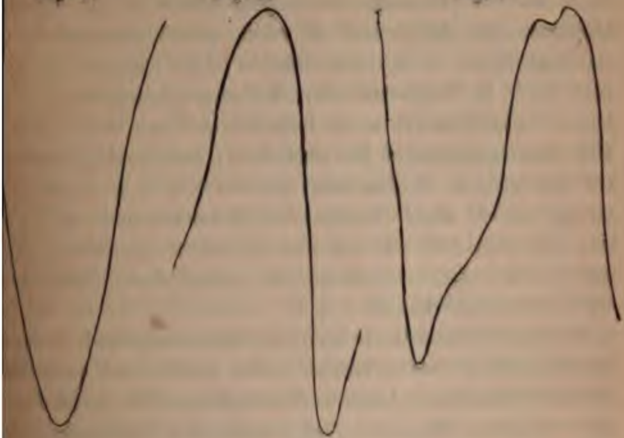
many as four floods have been noticed in one tide; but haps two of the most remarkable and interesting illustr of the disturbances superinduced by peculiarities in the fo any coast are to be found on the southern shore of Eng between Portland Race and Selsea Bill; and on the co France, a little to the south-east of this district, at the r of the river Seine.

At the western extremity of the British Channel the tidal wave from the Atlantic rises with considerable regu on both shores; but, as might be expected, the line of or rather isochronous, tides assumes a convex form to the east, on account of the diminution of velocity of its from the friction upon the shelving coasts. At Exmoutl St. Malo we find that the rise of the tide takes place great regularity, and in accordance with the deductions theory, as may be understood by reference to fig. 1, represents the curve of the tide at Exmouth, at the spr At the extremity of the Bill of Portland the same prevails, and the rise and fall of the tide are as near

* It has been found, however, necessary to insert the *times* upon th of the ordinates, because the spaces upon the chord-line were too sm receive them in the latter portion of the curve.

sible equal in time. The tide-wave continues its course, the northern edge at length meets the Needles Point,

Fig. 1. *Fig.* 2. *Fig.* 3.



here it divides into two unequal portions, one of which ntinues its course round the Isle of Wight, and the other ns up the Needles passage into the Solent. The velocity this smaller tide-wave becomes diminished considerably wing to the greater comparative influence of the friction pon the diminished volume), so that it only reaches Southmpton at the same time that the mid-channel tide reaches e point near Dunnose. The small tide-wave then begins to ll in the Southampton Water, but it is stopped in its descent the incoming tide derived from the main mid-channel ream which flows through the wide and deep passage of pithead, and, being driven back, the second high tide, repreented in fig. 3, ensues.

The Spithead tide in its turn divides at Calshot Castle, d, as it were, superposes itself upon the ebb tide for a conerable distance along the coast. At Yarmouth, the curve oduced is very similar to that noticed at Southampton, whilst

at Calshot Castle and at Lepe the two waves are so nearly identical in time, that the effect of the Spithead tide is only perceptible by the existence of a species of flattening of the curve. At Poole and Swanage the superposition of the Spithead tide upon the ebb, instead of taking place immediately after the high water of the first tide, is to be observed at about mid ebb. In Weymouth Bay, the same phenomenon occurs, but at a period intermediate between the base of the ebb and the commencement of the next flood; and at the Shambles, the last trace of the Spithead tide-wave is to be found in the strong current which flows, at the commencement of the ebb, in a direction from east to west, in direct opposition to the great tidal current, which at that period flows from west to east, or up the Channel.

Smeaton noticed the double tide, above described, at Christchurch; but we are indebted to the careful and remarkably skilful researches of Captain Sheringham, R.N., published in the "Nautical Magazine" for August and September, 1851, for the means of explaining this peculiar apparent anomaly in the tidal action upon our shores. It will be necessary hereafter to recur to this subject, in order to explain the practical influence of such phenomena upon engineering works.

On the French coast, and particularly in the Bay of the Seine, the high water is maintained for a longer period in the several ports of the embouchures of the rivers, than it is in the portions of the channel where the main tide-wave is sufficiently powerful to act in a normal manner. Thus, the tide remains at the full for the space of one hour at the embouchure of the Orne, and for $1\frac{1}{4}$ hour at the embouchure of the Seine; whilst at St. Malo, Dieppe, and Fécamp, it commences falling directly the culminating point has been attained. In these cases it appears that the impetus of the main ebb-tide wave, arising from its volume and velocity, is sufficient to prevent the escape of the small portions which had found their way into the irregularities of the coast, until

the level of the main stream had so considerably fallen as to allow the superior elevation of the in-shore waters to overcome the resistance of the main stream.

It must be observed that the outline of the ocean, upon the shores at least, is very far from being of the simple character it is usually considered to be. Not only is it modified by the tides, but also the latter are in their turn much affected by the configuration of the land. Thus, in the Bay of Weymouth, the great tide-wave sweeps past with great velocity, and it is only by what may be called derivation from the main stream that the water in the bottom of the bay is affected; and, in fact, at some periods of the tide, the water rather flows with an easterly current than in the ordinary westerly direction. If it were possible to level the mean surface of the tide-wave, we should, in all probability, find that a line would exist, passing from the extremity of the Portland Bill to St. Alban's Head, upon which the water would, during the flood-tide, occupy a ridge at a sensible elevation above that in the interior of the bay between those points. It must, indeed, be evident that the water, when once impressed with the motion of the tidal wave would, from its inertia, continue to follow its path in the direction thus given, until the superior force of gravity should cause it to flow into the lower positions withdrawn from the direct influence of the tide. Upon the tides in the Bay of the Seine this action is also very manifest, and the high ridge of the tide sweeps by the indent of the land, from the Cap de Barfleur to the Cap d'Antifer. In the intermediate portions the rise of the tide is only derived from the main stream, excepting at the mouth of the Seine in front of Havre; for the tide striking upon Cap d'Antifer divides into two portions, one of which continues up the channel, and the other returns along the shore, passes in front of Havre, and, joining the derived tide, runs up the Seine. On its course, however, this in-shore current is deflected by the jetty at the mouth of the Port of Havre, and is carried on to the Point du Hoc, where

it again divides, one portion flowing up the river, and the other returning close along the shore until it flows into the outer harbour. There are, in fact, no less than three strong tidal currents flowing in front of the port of Havre, each of which has a direction opposite to that of the current more towards the open sea than itself.

Finally, it is to be observed with respect to the tides, that they are so influenced by the outline of the shores and by the reigning winds, as also occasionally by local currents, that no abstract reasoning can be applied to them. As the relations between the times and the heights of the tides are of incalculable importance, both to the engineer and the navigator connected with any port, it is impossible to obtain too much information upon the subject. It would be, therefore, of the highest interest were consecutive observations carried on at all the important points of our coast.

Currents *.

The stability of works erected upon the sea-shore is often affected, directly or indirectly, by the action of currents; and the remarkable influence they possess upon the direction of alluvions, sand, or shingle, renders their study the more indispensable. Some of the most striking illustrations of the importance and nature of currents are subjoined.

In the Mediterranean there is a general current flowing along the shore, near the western end, whose direction is from the west to the east on the coast of Africa, and from the east to the west on the coast of Europe. On the French coast the velocity of this current does not exceed 3 inches per second, whilst at Algiers it has been noticed to flow at the rate of from 10 to 12 inches, or even as much as 40 inches, per second, at the extremities of some capes.

The oceanic currents are of much greater importance than that of the Mediterranean, on account of the immense

* See Rennell on Currents; Sganzin, Minard, Rennie, &c.

olume of water they roll along, and of their velocity; as kewise of their greater influence upon the climate of many ortions of the globe, and the serious interference they xercise upon the operations of sailors. The Atlantic curents are those with respect to which we possess the most ccurate information; and, indeed, it is probable that Major Rennell's surmise may be correct, that the outline of the hores of the Pacific is not so calculated to give rise to them s those of the Atlantic. The most important of the currents n the latter is the great Gulf stream, which sets round the Cape of Good Hope from the Pacific, along the western hore of Africa, until it meets the Bight of Benin, by which t is deflected to the opposite coast of America. Striking the xtreme eastern point of that continent at Cape St. Roque, t continues along the American shore to the head of the Gulf of Mexico, from which it flows through the Straits of Florida, following the eastern shore of the northern continent or a short distance, and a little below Newfoundland it urns off abruptly to the eastward. The main body of the Gulf stream is then deflected towards the south, and is lost near the Azores; but an important branch sets towards the direct east, and runs round Ireland and England, finally losing itself in the Arctic Ocean, near Spitzbergen. The effect of this stream is decidedly to contribute to the mildness and moisture of the climate naturally arising from our insular position.

On the western coast of France a current takes it rise, which flows in a southerly direction, along the coast of Africa, having, in its course, given off the stream before noticed as flowing into the Mediterranean: it is finally lost in the Bight of Biaffra. Major Rennell also was of opinion that a similar current also took its origin in the Bay of Biscay, and flowed in a north-easterly direction round the British Islands. It is, however, doubtful whether this be not merely the branch f the great Gulf stream already noticed.

The progression of the tide-wave creates a current, whose

direction, when observed near the shore, is very variable, although, as a general rule, it will be found to alternate, like the cause which gives rise to it. But it would appear that the change in the horizontal direction of the current by no means coincides invariably with the vertical change of the tide in time. There is an interval, more or less long, between the reversal of the direction of the current, and the epochs of the full or the low tide; and the coincidence, when it does occur, appears to be owing to some local and exceptional circumstance. Again, in some positions the direction of the tidal current varies through nearly all the points of the compass within the day (as, for instance, in the channel between Jersey, Guernsey, and the French coast); in other cases the variation only extends through a portion of the circle; whilst the normal change is only in the precise direction of the ebb and the flow.

As the principal lines of the tidal currents thus coincide with that of the progress of the great tidal wave, it must be evident that they would vary on each shore of the British Islands. On the southern shore they are principally from the south-west to the north-east, and *vice versâ*; on the western coast they are from S.S.W. to N.N.E., and *vice versâ*; on the eastern coast they are from N.N.W. to S.S.E., and *vice versâ*; which directions continue until the tide-wave which has passed round the northern part of Scotland and continued down the eastern coast, meets the tide-wave which has passed along the southern shore. But the influence of the configuration of the land upon the directions of currents is very perceptible in the shallow seas surrounding the British Islands; and it is therefore in similar positions more important to observe the nature and effects of local currents, than to adopt implicitly any merely abstract theoretical deductions. The peculiar laws of the tides, already alluded to as prevailing upon the coast between Portland Bill and Selsea Point, and in the Bay of the Seine, may be cited as instances of the modifications the outline of a coast is able

to produce in the direction of the tidal currents. Upon the southern coast of Great Britain another cause of irregularity exists in this, that the continuance of the south-west wind for a lengthened period will cause the tide to flow for an hour longer than usual, and in this manner give a preponderance to the direction of the current in the direction of the flood over that of the ebb.

The velocity of oceanic currents is not affected by the movement of the waves, for the advance of floating bodies within their influence takes place as rapidly when the sea is agitated as when it is calm; but the wind has very considerable power upon them, especially in their upper portions. It is also observed that occasionally there is a difference of direction between the upper and lower strata of currents, which may in all cases be accounted for by the interference of some local disturbance. The rate of flow varies within very considerable limits, as may be perceived from the following list of some of the most remarkable currents hitherto observed.

	ft.	in.		ft.	in.	
At the Ile d'Yeu, off the coast of La Vendée	1	8				per second.
At the harbour of Lorient	3	4				,,
,, ,, Cherbourg	4	8				,,
Off the coast of Alderney, sometimes	11	6	to	14	6	,,
,, south coast of England	5	0	to	10	0	,,
,, entrance to the port of Hâvre	5	0				,,
,, ,, ,, Dover	6	6				,,
,, ,, ,, Calais	7	10				,,
,, ,, ,, Dunkirk	4	8				,,
,, coast of the Orcades Islands	13	0	to	14	8	,,

The effect of the interference of any irregularity of the outline of a coast upon the direction of the currents is to produce a series of counter-currents, eddies, and whirlpools. It is admitted, therefore, that any abrupt projection or retreat from the general line, either of a current or of the bed of a river, will give rise to such counter-currents, whose destructive action upon the obstacles causing them will

have the greater intensity, in proportion to the g velocity of the stream. Capes, bays, and islands ar natural means by which these effects are produced on a scale. The jetties at the mouths of harbours have a pre similar action; and the changes they reciprocally pr upon the normal direction of the main currents require carefully studied, both by engineers and pilots.

At the embouchures of rivers the effect of the distu causes is further complicated by the dynamical tende the water of the current to flow into the depressions a existing in such positions at low tides, and by the desc the upland soft waters. The form of the embouchur considerable influence upon the phenomena to be met w any particular instance; for it may happen, and some does, that even when the tide falls, the sea water will tinue to be poured into the river; or *vice versâ*, tha river will discharge into the sea after the tide has comm rising; inasmuch as the conditions of the interchange waters depend upon the configuration and size of the pa Thus, at the mouth of the Adour, a river which, inste being open towards the sea, has a funnel shape wit neck outwards, the tidal wave maintains a greater heig the sea than in the river during the whole of the because it cannot enter through the narrow mouth sufficient rapidity to fill the bed of the river. The diffe of height has been noticed to be as much as four feet d the syzigies; and, in consequence of it, the duration flood-tide in the interior of the Adour is prolonged for an hour after it has ceased in the open sea. Anal effects have been observed at the mouth of the Ta Scotland, where also the embouchure is suddenly contra

A very peculiar and interesting phenomenon, before al to, may be observed during the rise of the tide in rivers such cases, as the molecules of the water pouring int river are impressed with a velocity equal to that of the tidal wave, their direction whilst flowing into the river

ntly be a resultant from the two directions of their nal flow, and that arising from the tendency of the water l up the depression of the embouchure. In the center ie principal current there will then be formed a line esponding with the axis of equilibrium of the forces icting the water up the river and towards the side. This arkable line is sometimes sufficiently defined to be visible he naked eye; and at all times it may be distinguished a broad sheet of stagnant water on either side; but it essarily changes, both in its direction and its form, accord- to the state of the tide, or the nature of the bed of the r. A precisely similar effect we have seen to take place ing the rise of the tide in certain bays; as in the cases re cited of the Bay of Weymouth and of the Seine; but mode of action may be more distinctly observed in rs.

'he descending fresh water interferes with the transmis- of the tidal wave up a river in the following manner:— soon as the flood begins to pour in it creates a species of , opposing the descent of the fresh water. Until the sea attained a greater height than that of the water so accu- lated, it cannot flow into the river; but as the rise of the is usually much more rapid than that of the land-waters, effect becomes quickly perceptible. In the mean time a es of zones of still water, of eddies, currents, and counter- rents, will be formed, in consequence of the opposite direc- s of the flow of the two waters, and of the difference in r specific gravities; and these irregularities will assume a ater importance, and a more permanent character, in portion as the volume and the velocity of the descending sh water is more considerable; and they will continue il the tidal wave shall have entirely overcome the resist- e of the downward current of the river.

It is on account of the interference of the descending sh water with the transmission of the tidal wave, that the urs of the flood and the ebb tides are retarded in propor-

tion as the distance from the sea increases; at the same time, however, the species of heaping up produced in them augments the difference of level. Indeed, from this cause it frequently happens that in the interior the tide rises to a point considerably above the level of the high tides in the ocean.

But the most singular phenomenon connected with the rise of the tide in rivers is the one presented by the "bore." According to Colonel Emy, this may be defined as being a peculiar undulation, which announces the arrival of the flood-tide in many rivers. It consists of two, three, or sometimes four waves, very short, and succeeding one another rapidly, which bar the whole river, and ascend it to a great distance; they often break upon the crown, and upset everything they meet in their course, and are accompanied by a fearful noise. In the Severn, the bore is stated to be of almost daily occurrence, and sometimes even to attain a height of 9 feet; in the Dordogne, it rises from 5 to 6 feet, and travels at the rate of about 5 miles in 34 minutes; in the Seine, it does not exceed 3 feet; in the Thames, it only exists in a rudimentary state; whilst in the Hoogly, at Calcutta, it rises about 5 feet, and is transmitted at the rate of about $17\frac{1}{2}$ miles per hour; and in the Menga the rise is said to be 12 feet.

The cause of the bore is universally considered to be owing to the interference with the transmission of the tidal wave, arising either from the sudden contraction of the embouchure of the river, or from the existence of some abrupt step or bar in the bed. The wave terminates abruptly on the inland side, because the quantity of water contained in it is so great, and its motion so rapid, that there is not sufficient time for the surface of the river to be raised immediately by the transmitted pressure. Mr. Whewell compares this abrupt tide-wave to those which curl over and break upon a shelving shore. The periods at which its effects are the greatest are at the syzigies; and they decrease in proportion as the bed of the river is deeper.

*Effect of Waves, Tides, and Currents upon Sea Coasts**.

The sea-shore, of whatever materials it be composed, if it e in the direction of any current, whether tidal or of any ther description, is gradually worn away by the incessant ction of the water. Under normal circumstances there is a ingular uniformity in the mode of this degradation; and qually in the cases of hard rock, of agglutinated shingle, or f clay; it will be found that, for a certain height above the evel of ordinary calm high tides, the outline of the shore ssumes a curvilinear form. Where the sea is much agitated, he height in question may attain from 13 to 14 feet; the urve itself is always cycloidal. At its foot, and tangentially to t, succeeds a slope, which joins the natural bed at the level of he lowest tides, with an inclination varying according to the ature of the beach. Sometimes the slope within the range f the tides is as 7 to 1; and it diminishes as frequently low the level of the low-water mark to as much as 30 to 1. t other times, and especially if the bed be of mud, the ope becomes almost abrupt below the low-water line, because e water supports the mud. At Cherbourg, it was noticed at the small materials thrown into the sea for the formation the breakwater took a slope of about 45° below that line; d in many cases upon our shores the shingle banks may be served to assume a similar inclination. In the Lake of eneva, the shore near Vevay, where it is composed of fine nd, takes a slope of 10 to 1, to a depth of from 6 to 7 feet low the variations of the water-line; whilst, at a greater pth, the slope is as 2 to 1, or the natural inclination of nd in still water.

The destructive action of the sea upon the shores unding it, arises principally from the action of the waves oving in the direction of the prevailing wind. This action complicated in its nature, but it may be considered to be

* See Lamblardie, Sganzin, Minard, Smeaton, &c.

composed of the oscillating motion of the molecules of the water occasioned by the waves; of the effect produced by the wind upon the upper parts of the waves themselves; of the reaction produced by any projection beyond the ordinary line of the shore; of the permanent and periodical currents to which the mass of the water may be exposed; and, finally, of the dynamical effort exercised by the water set in motion. Of these causes, the three first are without comparison the most powerful, and hitherto it has not been ascertained within what limits they are able to act. But it is important to observe, that the existence of any object in abrupt relief gives rise to such eddies, that the bottom of the sea round it will be rapidly carried away, if it be of a nature to yield easily, and be situated within the limits of the disturbing causes. It follows from this, that great precautions must be taken in the construction of any vertical retaining wall whose foundations may be near the low-tide line; for the repercussion of the waves is certain to undermine them, if formed in clay or light sand.

Occasionally it may happen that the destructive action of the sea, which principally operates in the direction of the advance of the flood-tide, is reversed by the existence of some local current which increases the power of the ebb. Thus in the British Channel the outline of the majority of the bays between Land's End and Portland Bill is concave towards the incoming tide; but between Portland Bill and Selsea Point, the outline of the bays, of the main land at least, is almost invariably convex to this tide. The cause of this apparent anomaly is to be found in the existence of the second tide before noticed, which increases the volume of the ebb close in shore; and also to the fact that the island of Portland, and the spur terminated by St. Alban's Head, form, as it were, breakwaters sheltering the intermediate district from the effects of the south-west winds.

The geological nature of the rocks exposed to the fury of the waves may also materially affect their rate of destruction,

also react upon the preservation of the neighbouring res. In the particular instance last cited a remarkable mple of this may be found; for the projecting points of Isle of Portland and St. Alban's Head are respectively the harder and more resisting strata of the oolite; whilst intermediate bays of Weymouth and of Poole are exvated in the less resisting strata of the Oxford, or the Lonn, clays.

Similar observations are to be made upon the configuration the French coast in the Bay of the Seine. Its general tline is concave towards the north-east, on account, doubtsly, of the increased force of the ebb-tide, arising from the flected portion of the flood striking the Cap d'Antifer, and m the volume of the several rivers, Seine, Orne, Touques, ves, Vire, &c., which pour their waters into it. From the t also that the western extremity of the bay is formed by granitic peninsula of the Cotentin, projecting far into the itish Channel, this portion is sheltered from the first lence of the great tidal wave, and also from the effects of prevailing winds over the vast expanse of the Atlantic. yond the Cap d'Antifer, as also beyond Selsea Point, the in outlines of the bays resume their normal direction; and y are concave towards the incoming flood-tides. These servations, however, must only be understood generally, cause there are innumerable causes of interference with action of the usual laws, which may be observed to affect riously every particular locality.

The materials detached from the rocks or shores by the are transported by the currents in a direction which may stated generally to correspond with that of their greatest d most permanent influence, whether that be in the same e as the advance of the great tide-wave or in the opposite e. Thus upon the French coast the materials detached om the cliffs, in the portion situated near Cap d'Antifer, e transported partly towards the east, and partly towards e west, in consequence of the separation of the tidal cur-

rent at that point, and the normal direction of the ba the mouths of the harbours will be found to correspond these directions; that is to say, the shingle enters the of Etretat, Fécamp, and Dieppe, from the west; whilst carried into Hâvre and Honfleur from the east, and the of the Orne and the Vire have a general inclination a the mouths of the rivers from east to west. Between La End and Portland the shingle moves from west to east the tidal current, and again beyond Selsea Point to Foreland the same fact may be observed; but, in oppos to the generally received opinion, it will be found that bulk of the shingle moving along the coast between Port and the Needles, moves from east to west, and that the r direction of the bars is also between those points. The currents of this part of our shore are, however, so extrem complicated, that it is hardly possible to affirm that positive law exists with respect to the distribution of shingle upon it; and, indeed, the prevalence of a south- wind for a few days will totally reverse the ordinary condit of its advance.

However, it will be found that, in every possible direc of the progress of the shingle or other detrital matters, current will deposit them upon its concave edge, whe is deflected by any object from its ordinary path. This be accounted for by the fact that the mass of water in main current will be animated by a certain velocity, w will carry it forward in its original direction; when, there it is diverted from its course, the change will take place curvilinear form, derived from the original impulse, and tendency to rush into the depression existing behind obstacle. The main body of the stream, under such cir stances, will retain its velocity, but the edge near the obs will flow more slowly by the effect of the friction and retardation caused by a portion of the water flowing into depression. In consequence of this diminished velocity stream will no longer be able to transport the shingle, w

ecessarily be deposited on the line corresponding with tardation. The Italian authors upon hydraulics have bserved, that when the wind blows in the same direction hat of the littoral current, sand-banks are more rapidly d in the sheltered parts of the shore than under other nstances.

e shingle, or other alluvions, which surround the bases of follow precisely the contours and directions of the latter an. But when the shingle collected in a bay has no sic support, it will assume a curvilinear outline, whose vity will be turned towards the sea, in the direction of revailing wind. This effect may be distinctly perceived me of the bays upon the eastern shores of England, pon the French coast between the Caps d'Antifer and ez; for in both cases the yielding nature of the mate- allows the general outline of the coast to modify itself e most powerful action of the waves, which, as is well n, is always exercised in the direction of the prevailing . On some parts of the French coast M. Lamblardie the concavity to be nearly one-tenth of the chord line e bay. It also appears from his observations, and from of Zendrini, upon the shores of the Mediterranean, the advance of immersed substances, and of detrital er in suspension, may be owing either entirely to the n of the waves, or to that of periodical currents, or to a ination of both. When the direction of the prevailing and of the waves is perpendicular to the shore, the sive action attains its maximum, but no movement of lation is given to the detritus along shore. When the tion of the wind is parallel to the shore, the action upon hingle is at the minimum; and Lamblardie asserts, that that direction forms an angle of 45° with the shore, the n to produce the movement of translation attains its imum. If, therefore, a bay exist whose central axis ld correspond with the direction of the prevailing winds, alluvions driven along the coast will be accumulated at

the bottom of the bay; and if a projecting mass of s should be exposed to such a wind, the materials of wh is composed would be carried from it on either side summit.

As might naturally be expected, it is found that direction of the littoral currents corresponds with that prevailing winds, the advance of shingle or other all is more rapid; and, in fine weather, the translation smaller materials may still continue. But if the two should be in opposition to one another, there will en diminution, or even a temporary or a permanent cessati the onward movement.

If, during their advance along the shore under the impulsion of the waves and of the currents, the all meet a deep bay sheltered from the prevailing wind still water existing in it will allow the heavier partic subside; and if, in addition to the general comparative quillity of the bay, there should exist any subsidiary cur producing upon their edges zones of still water, the re ing matters in suspension will be deposited either temp or permanently. This latter contingency occurs in th bouchures of most rivers, and the bars are formed, in cases, by the deposition of the alluvions upon the l junction of the littoral current with that of the down st and, as these directions are usually either at right ang highly inclined, to one another, the axis of the bar f that of the resultant affected by the volume, the velocit the direction of the two streams.

Should the alluvions, instead of meeting with a dee such as has been described, meet with a projection upon the shore, they will form a deposit in the opposing angle which will be concave to the general direction of their advance. If the action giving rise to the alluvions be permanent, it will eve

rry them round the projection, and there, meeting with still ater, they will be deposited. The accumulation of a bank n this position will often be accelerated by the currents and ounter-currents generated by the projection.

The conditions of the advance and deposition of marine lluvions are complicated by many interferences, in the mouths f rivers, beyond those already alluded to. For not only are hey affected by the outlines of the coast, and the meeting of he currents, but also by the differences in the specific ravities of the waters, and by the sediments brought down y the rivers themselves. According to the particular period f the tides, there is an alternate predominance in the effective ction of the two waters; and the occasional occurrence of land oods still further modifies them, thereby complicating to a uch greater extent the phenomena of the formation of ravel or mud banks in what are called the "deltas" of vers. This subject is treated with remarkable ability in ir H. de la Beche's "Geological Observer," and the reader therefore earnestly referred to it; but it may suffice for our esent purposes to observe, that long and patient observations quire to be made before any engineering works should be dertaken, with a view to modify the conditions of the position of the banks in the embouchures of rivers. If, on e one hand, the narrowing the channel be advantageous, confining the waters in an invariable direction, and by epening the passage by the increased velocity thus obtained; may, on the other, also diminish the quantity of water troduced at every tide into the upper reaches of the river, d interfere with the discharge of the floods.

The extent of complication, so to speak, of the causes aring upon the deposition of alluvions in embouchures is great, that, in the present state of our knowledge, nothing n be predicated with certainty as to the effect of any odifications upon their outline, whether produced by nature by art. It seems, therefore, advisable, unless there be me exceptional circumstances attached to the particular

case which may be under consideration, to adopt merely temporary methods of removing the deposit which may obstruct them, rather than to construct expensive works with the hope of controlling the powerful and unknown operations of nature.

In tideless seas, such as the Mediterranean and the Gulf of Mexico, the littoral current is not sufficiently powerful to counteract the influence of the waves and of the reigning winds, or at least it can only carry forward the materials already in motion. The deposits of alluvion in such seas, then, are only regulated by the winds and the waves along the open coasts. In the embouchures, the matters in suspension in the river waters are thrown down gradually, and in the order of their specific gravities, at the points where the velocity of the soft water ceases to be sufficient to bear them along.

It appears to be generally admitted by the Italian, French, and German engineers, that where sand-banks have once begun to form naturally, it would be in vain to endeavour to prevent their continued increase. All their efforts are therefore directed simply to fix such banks as may exist, in the positions where they are likely to be the least injurious, and where any additional accumulation may be easily removed by dredging. At the port of Cette, on the French shore of the Mediterranean, artificial means have been employed to provoke, as it were, their deposition in certain positions, but the result hitherto has been problematical. It appears, also, that the observations of the Italian engineers have led them to the conclusion, that the best position for ports in seas like the Mediterranean, so far as regards their freedom from alluvial deposits, is one in which a natural bay may exist, without a river, or other cause of interference with the current. The bay should also be placed in a direction opposite, not only to the littoral current, but also to that of the prevailing winds.

Some very striking illustrations of the importance of the

cts produced by the alluvions set in motion by the sea, ether they consist of shingle, sand, or silt, may be found n almost every shore. On the coast of Kent, two deep entations upon the outline of the land, at Romney Marsh l Pegwell Bay, have been filled in. On the coast of rfolk, Lowestoff Ness is also gradually gaining upon the , from the deposition caused by an interference with the gress of the shingle. In the Mediterranean, the ports of gues, Mortes, and of Fréjus, from which the armies of St. uis embarked, are now far inland, and are only kept open small vessels by means of constant dredging. The port Ostium, at the mouth of the Tiber, formed by Claudius d repaired by Trajanus, is now about three miles from the . The lagunes of Venice tend naturally to silt up, and only kept open by means of the artificial channels con-ucted for the purpose of carrying the waters of the several ers Brenta, Bachelone, Piave, and the Sile, more directly o the open sea of the Adriatic. Illustrations of the sions produced by the action of the waves may also be ind on every shore; the reader who would desire to study is branch of our subject more thoroughly is, however, ferred to Lyell's "Geology," and to De la Beche's "Geo-gical Observer" for further details.

The materials detached from the cliffs undermined in this nner are rolled forward continually, and under the in-ence of this friction they become comminuted at length a fine sand. In some cases the sand, earth, and broken ells deposited by the high spring tides are carried inland by e wind, and advance in waves nearly as strongly defined as ose upon water. If any obstacle be offered to their progress, ey accumulate to a vast height, and occasionally they spread er a great extent of land on either side. Thus, in the Landes Bordeaux, hillocks of sand are said to have been formed, aining a height of about 160 feet; and the sands advanced wards the interior at the rate of about 33 feet per annum,

until Brémontier commenced the series of works for the purpose of fixing them which has contributed so much to immortalize his name. In the case of the Landes of Bordeaux, the progress of the sand was accelerated by the dryness of the atmosphere; but upon our own coasts, in Poole Harbour, and on the French coasts, near Dunkirk, the rain-fall, and perhaps also the presence of a considerable quantity of earth in conjunction with the silicious sands, develops a peculiar vegetation which prevents the further progress of these downs, or dunes, as they are called in France and Belgium. The principal measures adopted by Brémontier consisted in planting the sand reed (*Arundo arenaria*) for a distance of about 300 yards from the sea. For a second zone, of about 1000 feet in width, he planted creeping plants, brambles, heaths, &c.; and more inland, at a distance beyond the influence of the salt water, he planted a zone of fir trees. It appears, however, that the fixing the landes near the plains of Soulac and Thalais, on the sea-shore to the south of the Gironde, has produced a considerable effect in the action of the sea upon the outline of the coast. The very incoherence of the sands appears to have prevented their removal, seawards at least.

Defence of Shores.

The foregoing general observations upon the action of the sea upon the coasts, or works exposed to its effects, are necessary to a complete knowledge of the most advisable means to be adopted for their protection. With respect to the defence of coasts, it follows, from what has been said, that the works to be executed must consist either of such as are able to break the force of the waves before they reach the shore; or of such as are able to consolidate the shore itself, so as to enable it to resist more effectually the denudation produced by the waves; or of such means as shall cause an

accumulation of sand and shingle upon the fore shore. Under some circumstances it may be advisable to combine the three descriptions of works.

The construction of groins firmly connected with the shore, and following a direction normal to that of the reigning winds in tempestuous weather, whether they be submersible or not, would diminish the action of the waves; particularly if they be carried out so far as to prevent the species of cascade, which always takes place on their downside, from affecting the shore itself. In some cases isolated pillars of masonry or timber-framing, placed like the squares of a chess-board, by causing the waves to break seawards, may become very efficient means of defence. On the coast of Holland very successful results have been obtained by the erection of wooden framing placed in a parallel direction to that of the

coast at the line of low water. In soils susceptible of being easily removed, however, it is indispensable to protect the foundations of these groins by apron pieces.

The consolidation of a shore must be performed in very different manners under different circumstances. If the natural inclination above low-water mark, up to the extreme point reached by the waves during tempestuous weather, be abrupt, it will probably be found more advantageous to interpose a vertical wall or defence, whether of masonry or of wood-work. In the former case the stones should be laid as headers, and the upper parts coped with the largest stones it is possible to procure, also laid as headers; and it would be advisable to pave for a distance of some 8 or 10 feet beyond the coping, so as to throw off effectually any water breaking over the wall.

The footings must also be protected by rubble stone-work, by an apron bedded in mortar.

In Holland, however, the dykes are very frequently forn as represented in the sketches here given, the body of

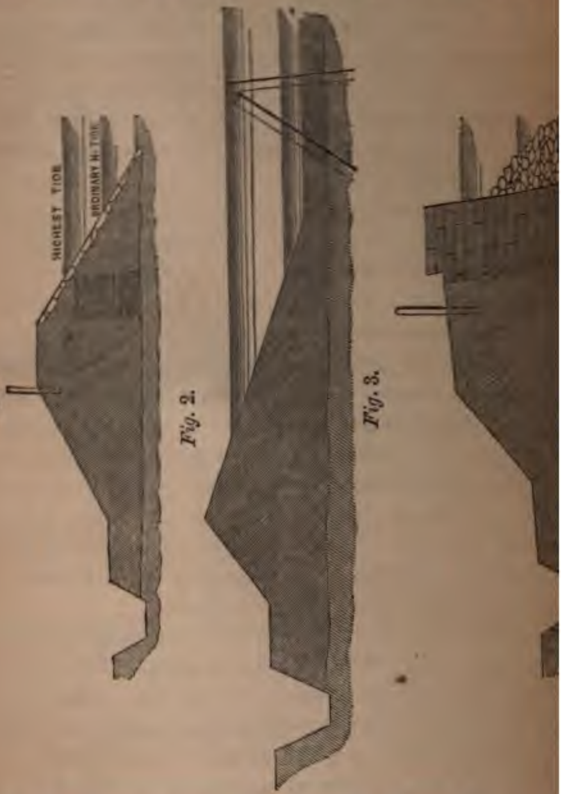


Fig. 1. Fig. 2. Fig. 3.

embankment being of earth with a hearting of fascines, bundles of reeds in some cases, or with a facing of si materials in others, protected at the foot by rubble-st Or, again, the whole of the embankment may be in e work, with or without any provision to break the force c

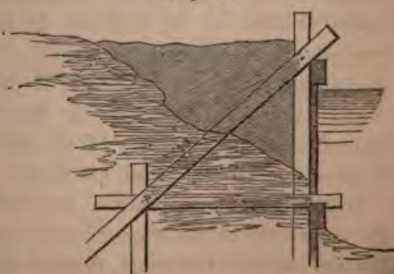
ves. Many instances may be mentioned where the banks the polders are formed in a manner similar to a coffer-

Fig. 4.

Fig. .

Fig. 6.

Fig. 7.



n, by means of a ddle-dyke retained ween sheet piling. Hâvre, the mode ich proved most cessful consisted forming an em- kment of earth- k behind a ver- l inclosure of

sheet piling, with a loose rubble apron at the foot, or even, in the positions where the scouring effects of the current were very great, with an apron of solid masonry. The general form of the sea defences of the plains near Hâvre is represented in the sketch fig. 7.

The remarkable success of the dykes formed with long slopes upon the fore shore, in the manner of the Dutch engineers, would seem at first sight to be inexplicable if the principles adopted in such cases as the one cited immediately after them be correct. But it happens in this instance, as in so many others to be encountered in engineering, that circumstances seriously modify the application of purely theoretical deductions. Unquestionably sea walls presenting a vertical face to the action of the waves are more capable of resisting their effort, provided the foundations be good, than when they present a long inclined face; because the sea is, in the latter instance, carried to a much greater height, and breaks with greater force upon the shelving shore, than when its effort is destroyed by a resistance acting more directly in opposition to its own. But the repercussion of the waves dashing against an obstacle of the description of a vertical wall, creates so great a tendency to undermine its foundations, that it appears demonstrated by experience that they only resist when placed at such a depth as to be below the usual range of disturbance by the waves, or upon the condition of repairing them constantly. If a coast, then, be bathed by deep water, and present steep escarpments, the works erected for its defence, as before stated, should be vertical; if the fore shore should present a long slope, the works erected for the protection of the land must be made in continuation of it, adopting as the limit of inclination for embankments in stiff clay 10 on the base to 1 in height, and in loose fine sand as much as 20 base to 1 height.

It is important to observe that, whatever form be given to the embankment, its crown must be carried above the level of the sea during the most disturbed periods; for the water

reaking over the crown softens and carries away the backing, of earth-work especially, and gives rise to settlements of a ery dangerous character.

Owing to some local considerations, it may occasionally be referable not to form the slope of the embankment with so ide a base. In such cases it will be necessary to protect it ith a facing, the materials of which will be regulated upon he simple ground of economy. They may be either of carentry, of fascines, reeds, or of stone pitching; the most mportant element in the decision of the question being, that he maintenance should be assured, without danger of inerruption. The portion of the pitching or facing coreponding with the plane of the half-tides requires to be trengthened, because it is about that height that the waves nd currents exercise their greatest power. Moreover, as the olidity of an embankment can only be depended upon when t is founded upon a rock or upon some stratum able to esist the action of the sea; and as the inclination of the ore shore always depends upon the configuration of the oasts, and the inequalities and nature of the soil in which it s formed, it becomes indispensable that all the variable condiions these are likely to assume should be carefully examined efore commencing such works.

Upon the shores bathed by currents carrying much alluvial natter, it is possible to retain this by means of groins raised above the high-water line, or by shingle traps, or by groins ubmersible at half tide. The effect of these constructions will be precisely analogous to that of the supposed obstacle to the onward movement of alluvions before described; the hingle will be accumulated on the up side of the groin (that s to say, in a direction meeting that of the current) until it as filled in the angle. It will then pass round the point nd accumulate in the still water behind the groin on the own side. A curious effect is, however, often produced by he erection of these works, viz., that the corrosion of the hore takes place with greater violence beyond the point

where the protective influence of the last groin is felt, that it possessed previously to their erection. The materials to be employed in the construction of groins should be of the most economical nature, as they are rarely intended to occupy their positions permanently.

Construction of Piers and Breakwaters.

The construction of piers, jetties, and breakwaters, is much influenced by the considerations of the effects of winds, tides, and currents, above described. The objects they are proposed to effect are to procure tranquillity in the interior of ports, and at the same time to facilitate the manœuvres of shipping entering or leaving them. To explain the details connected with such works, it becomes, therefore, necessary to dwell somewhat at length upon the general character and description of ports to which they form such important adjuncts.

It is usual to designate by the term "port" a space of water in connection with the sea, of variable dimensions, and of depths either constant or variable, in which ships may obtain shelter from tempests or from an enemy, repair any damage they may have received, or discharge and replace their cargoes. Such ports may be either upon the immediate sea-coast, or at some distance from the mouth of a river. The former, again, may either possess a broad expanse of sheltered sea, or, as they are called, roads; or they may be placed upon unprotected open shores. Roads also may be natural or artificial, open or sheltered, according to the configuration of the coast, and of the bed of the sea in the particular direction under consideration. But of whatever description they may be, their utility mainly depends upon their possessing a sufficient depth of water for a vessel to ride at anchor at any time of the tides; whilst the bottom must be sufficiently firm to allow the anchors to hold in a storm. If such roads have convenient access, they facilitate commerce by

; calling stations where vessels may wait for orders, or they may wait for the winds or tides requisite to carry nto harbour.

roads and ports may be further subclassified into ithout tides and those with tides, according as they situated upon waters affected or not by that semi- inequality. The ports upon the Mediterranean, the Mexico, the Caspian, and the great fresh-water lakes, considered as of the former class; those upon the of the ocean as of the latter. Practically, also, the to which roads and ports are specially appropriated e to a further separation into the respective classes of rcial and military.

variable degree in which harbours are affected by the oduces a marked difference in the influence of roads eir utility. For if the interior of the harbours should ssess a sufficient depth of water at low tides to allow to enter, evidently it will be necessary that these wait until a favourable moment should arrive, and this nly be effected in a road close to the mouth of the r. As the larger class of vessels are not constructed the ground, as it is called, or to lie high and dry n the intervals of the tides, it becomes necessary to ct floating docks to receive them in all ports so cir- nced.

utility of roads, whether open or sheltered, must of depend upon the number of vessels they are able to nodate. Sufficient space must be left round each vessel w of its swinging upon its anchor, according to the s of the winds or the tides, without its being exposed any other vessel. It is usual to calculate upon a of two cables' length for ships of war, and of about at radius for merchant vessels.

ccount of the great space thus required, roads cannot irely formed by artificial means; they must exist ly, in a more or less perfect state. It is, howev

possible to improve such as may exist, by the constr
breakwaters or of jetties, so as to shelter any portion
to the violent action of storms; or by dredging any
increase the available surface for anchorage. The
Plymouth, Cherbourg, Cette, and at the mouth of
laware in the United States, may be cited as illustr
what has been done to create an artificial shelter; w
port of Nieuwe Diep, on the Zuiderzee, and of
may illustrate the methods employed to clear an
existing roadstead. There were, however, some pec
attached to the amelioration of the port of Nieuw
which require to be noticed hereafter a little in detail

The most advantageous situation for a port is at
tremity of a roadstead, especially if the channel of c
cation assumes a tortuous form. Should this not be
it will be necessary to construct piers, jetties, or m
destroy the undulations communicated by the open se
also of vital importance for the security of a port
should be surrounded by high lands on the in-s
guarantee vessels from the effects of the winds blow
that direction.

As the piers at the mouths of harbours are construc
a view to facilitate the manœuvres of vessels, it i
preferable to make greater provisions to assist the
than their departure. A vessel in harbour can alw
for favourable weather; whilst those coming in from t
sea may often be driven in by stress of weather. In
harbours, also, it is necessary to place the piers so t
may coincide with the direction of the currents, and i
manner that the ships should not be carried again
whilst passing to the interior. Of course this precau
require to be observed in tideless harbours, if any d
marked littoral current should exist; but it is of more
importance where the currents flow in alternate di
than where they are permanent. It is to be observ
r, that the manner in which vessels are towed o

rior of a port will influence the form of the piers to a extent. Because if the vessels are towed in by men, ed in by a rope, the piers must be carried out so far y should be able to make their first tack without pon the opposite side; whilst if the vessels be towed steamers, the extension of the piers need only be d by the necessity for protecting the entry of the from the effects of the currents.

e constructing any pier or jetty, it is essential to study vement of the alluvions upon the coast upon which to be placed. They frequently produce the effect lescribed as attached to other projections upon the that is to say, they give rise to depositions of shingle nd, susceptible of diminishing the depth of water at ance, or even of accumulating silt in the harbour to extent as to close it entirely.

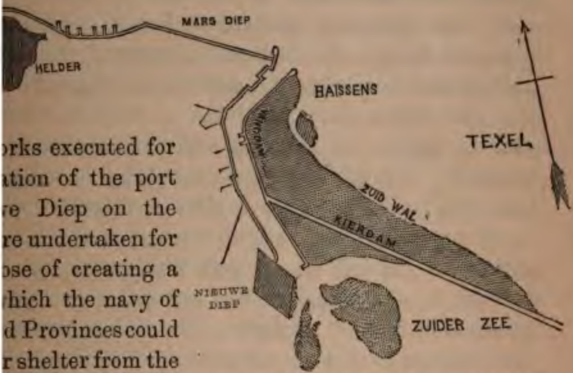
e shores of the Mediterranean this tendency of jetties ce the silting up of harbours is so strongly marked, been observed so long, that the ancient Romans a peculiar construction with a view to obviate it. ilt their moles, in fact, in a series of piers and arches, the open spaces of which the sea passed, without ts agitation or its littoral current. Vauban appears considered this mode of construction to have been t advisable in similar positions, and of late years one nost distinguished Neapolitan engineers, M. Fazio, lled the attention of the profession to the subject in a ion of singular merit, entitled "Discorse trè intorno or Sistema di Costruzione de' Porti." Napoli, 1828. tem he recommended is represented in the accom. sketch; but it is far from being demonstrated that ilts obtained upon the Neapolitan shore would be in others. Open moles do, indeed, allow the littoral to act partially; but the feeble portion which remains transport the alluvions when the sea is sufficiently

agitated to maintain them in suspension; so that the agi
of the sea appears to be necessary to maintain the de
water. It follows, therefore, that the more effectuall
open moles shelter the interior of the harbour, the less
are they to produce the desired object of preventing i
becoming silted up.

During the last century, and even in many cases
present day, the means resorted to for obviating the g
shoaling of harbours was to construct artificial back
with sluice gates. But, however powerful they may
results obtained by them are always unsatisfactory, b
the sand or silt removed by them is invariably thrown
at a short distance from the point where the stream fr
sluice has its velocity destroyed by that of the littoral c
at which point a bar will be formed, usually across the
of the harbour. The history of such ports as Dover,
stone, Newhaven, Fécamp, Brighton, Dieppe, Havr
Ostend, demonstrates the inefficiency of all such me
combating the tendency to fill up indentations on the
of a coast situated upon the line of advance of alluvio
in motion by a strong littoral tide. But at Nieuwe Di
Dutch engineers, by combining the direction of their
so as to obtain at the same time the benefit of the sc
power of the tides, succeeded in forming and maintai
new channel to a natural harbour through what pre
was a very extensive sand-bank. In all these cases it

ng the action of natural causes that success can be ; the few artificial means at our disposal are power- e the operations of nature.

French ports, so strongly does the conviction of the f sluicing prevail, that the engineers have almost abandoned it. Their efforts are now directed to the amount of shingle annually brought in, and to t by dredging in the most economical manner; re to deposit the silt in such positions as shall not ts being brought back into the harbour.



orks executed for ation of the port re Diep on the re undertaken for ose of creating a hich the navy of d Provinces could r shelter from the d floating ice which render that part of the coast so s in winter. A shallow pass existed between the land Holland and a sand-bank, called the Zuid Wal, which the Zuiderzee from the Texel, and converted the to a secure roadstead; but the depth of water in the only about from 12 to 13 feet deep at high water. nt of the proposed operations rendered the use of ging machinery known at the epoch (1781) inap- the Chevalier Brunings therefore adopted the f directing the flow of the tide-wave between a dykes, so as to concentrate its action upon those of the pass where it was desired to obtain the *depth.*

The Zuid Wal was originally about from 3 to 4 feet the level of high tides, and from 20 to 30 inches abov water; the tides rise in front of the town of Helder 5 feet 3 inches and in the Nieuwe Diep about 4 feet 5 i on the average. It was observed that whilst the ba under water the velocity of the current in the pass was but that it acquired much greater force about the ends tides, especially at the ebbs. A larger quantity of was therefore made to follow the channel intended deepened, by constructing a jetty, or rampart, on the side of the sand-bank; it was entirely above water, nearly two miles long upon the bank itself, with an ex to a point beyond the northern entrance of the military bour of about two-thirds of a mile. Some perpendicular j were also placed upon the dykes on the western side port, to confine the scouring action of the current in direction. A submersible dyke was placed on the edge Zuid Wal (a keerdam) which allowed the water to flo in either direction at certain periods of the tides. portions of the bed of the pass which were not able removed by the action of the current, were loosened species of harrow, or dredged. The results produced b works were such that in the year 1794 the depth of wa the pass was not less than from 26 to 33 feet, and in parts as much as 40 feet, at the low tides; and so judici had they been executed that the total cost had not exc 150,000*l.* Subsequently the basin was constructed, and under the government of Napoleon and of the late Ki Holland, the town of Nieuwe Diep has continually incr in importance.

Reverting to the considerations affecting the positio piers or jetties, they will be found to depend upon following general conditions:—the direction of the prev winds, of the currents, and upon the progress of the allu the depth of the sea, the size intended to be given t port, and the character of vessels the latter is intend

ceive; together with the necessity for facilitating the entry departure. The captains and pilots frequenting the port e the parties who are most likely to possess accurate formation upon these points; but, in addition to this, it is dispensable to have soundings taken not only on the im- ediate site of the proposed jetty, but also to a considerable istance if any bar exist.

A jetty placed at an angle of 12° with the direction of the igning wind, is usually found to afford the greatest facilities r the manœuvres of shipping. The length need hardly xceed the extreme low-water line, although unquestionably e entry would be safer if the jetty were carried further out. t is very rarely, however, that the advantage thus gained ill compensate for the increased expense of executing the asonry under water.

If two jetties be required, it is advisable to make the one mediately under the prevailing wind longer than the other; ut there are circumstances which may materially modify the plication of this rule, or even reverse it entirely. Thus, e commercial port of Cherbourg has the windward jetty orter than the leeward, for the following reasons:—the port principally resorted to as a refuge in stormy weather, and the storms upon this coast come principally from the west, ey are more unfavourable for vessels standing *down* than for ose standing *up* the Channel; because the latter can either n past, or make a port further east; whilst Cherbourg itself the last port of refuge vessels standing down channel, on e south shore, can make. The port is therefore used incipally by outward-bound vessels, and directly the wind ifts to the east all those in the harbour leave as rapidly as ssible. It is customary to perform the hauling by men, d to carry the vessels out so far that they shall be able to their first tack clear of the western jetty; the eastern, leeward, jetty, therefore, has been carried out beyond it, in ler that two or three vessels may leave at the same time.

Belidor was of opinion that if the line of direction of the jetties cut that of the littoral current, it was advisable to make the upper one shorter than the lower, because he conceived that the water striking the advanced portion would be reflected and produce a species of counter-current favourable to the entry of the port. But Minard justly observes that this object will be equally attained by the prolongation of the upper jetty, because the indraught of the port will create a back current. The length to be given to the jetties will therefore be decided by considerations independent of this particular one.

The disposition of jetties, in plan, is a point upon which great diversity of opinion exists amongst engineers. For some reasons it appears desirable to construct them on two curved parallel lines, until near the extremity, with the convex side turned towards the direction of the progress of the alluvions. In this case the scouring action of the water from the inner harbour, whether produced by sluices or simply by the tidal action, will be more effectual against the bar which usually forms at the head of the inner jetty, by the centrifugal force of the water deflected from the outer side. Moreover, this disposition is more favourable for the protection of the interior of the harbour from the effects of the wind.

But if the jetties be executed in smooth dressed masonry, the transmission of the waves takes place with undiminished intensity. The Romans appear to have noticed this effect, for all the old ports of the Mediterranean have a polygonal form, and it has evidently been an object with their engineers to avoid joining the several straight lines by curves filling in the angles. On the other hand, it was noticed in the port of Hâvre that the waves were reflected from the opposite faces of the jetties, which were constructed of this polygonal form, and the manœuvres of the vessels were much impeded by the constant changes in the direction of the waves thus produced.

ensible improvement in quillity of the outer har- s been produced by the tion of an open timber ter, backed by a shelving f masonry, upon which es, whether driven in or merely reflected e opposite jetty, lose a rtion of their power. A system had previously ied at the entry of the Dieppe (see sketch in where likewise it met isiderable success.

width usually given to nnel between the jetties entrance of a harbour is ich shall be sufficient to he passage of three of est ships frequenting it, il, and at the same time. imum may vary between l 240 feet, according to of the ships and to the of the sluices. At the ties the width should be d; because the ships more room to perform olutions whilst under the e of the way they carry the open sea, than when ve followed the narrow for some time. The introduction of steam-tugs has r a greater width of channel than was required under system.

The roadway of the jetties should be finished off at a height sufficient to guarantee the men employed upon them from the effects of the sea in ordinary states of the weather. From 7 to 9 feet above high water spring tides will be sufficient; but the extremity, or the head, must be raised about 2 feet higher than the remaining portion. The heads or extreme ends, may be erected with a width at the crown of from 27 to 36 or 40 feet; whilst the intermediate parts may vary from 7 to 20 feet, according to the materials employed. When the jetties are in wood, the smaller dimensions are employed; stone jetties are very rarely made less than 12 feet wide upon the line of the pavement.

The form to be given to the transverse section of a jetty is regulated by the nature of the materials employed in its construction, as much as by the dynamical effect of the waves. The materials may be either wood, loose rubble-stone, or solid masonry bedded in mortar.

Wooden jetties may be entirely open, or filled in with rubble either entirely or partially; or occasionally they are placed upon the crown of a subsidiary jetty, finishing at a point below the high-water line, which is executed in rubble masonry or loose stones. The lower part of the majority of wooden jetties is, however, covered either by a mass of concrete, of loose stones, or of fascines, dressed with slopes both to the seaward and the inside of the harbour, forming a kind of ledge which serves to defend the foundations.

The frames of such jetties are placed at distances apart of from 6 to 10 feet, according to the depth of water and the habitual agitation of the position in which they are to be placed. They are made in the form of a trapezium, the inclined sides being respectively turned towards the chan-

nel and the open sea, and forming with the vertical line an angle of from 13° to 33°. The timbers consist of two or three posts, tied together by horizontal clipping pieces, with raking struts or braces, forming with the horizontal ties a system of triangles. Wales, cills, and heads tie these separate frames together longitudinally. In the best works of this description lately executed, all the joints are made by halving and bolting, for it is found that the continual motion of the waves causes the tenons to work in the mortices wherever that style of joint is used, and that there is no effectual way of remedying the loosening thus produced; whilst, if the joints be halved and bolted, they may be tightened up by screwing the bolts, should they have worn. All the wood-work should be tarred, and precautions must be taken to defend it from the attacks of the boring worms, whose ravages will be noticed hereafter.

The upper sills carry joists, upon which is laid a planking, usually from 4 to 5 inches thick, and with spaces of about 1 to $1\frac{1}{4}$ inch wide between each plank, to allow of the escape of any water breaking over them. The planks are spiked down to the joists, and a species of bridging or tying-down joist is bolted upon their extremities to the sill resting immediately upon the framework.

When the jetties are filled in with rubble-stone, the cases to retain the latter are formed by close boards, laid horizontally against the upright posts. The interior is filled in sometimes with shingle, sand, or clay, as well as with stone, and the recent application of Portland cement concrete in the execution of such works appears likely to exercise important effects upon this branch of construction. The best position for the horizontal planking appears to be upon the outside of the posts, because, although when it is placed upon the inside it resists the thrust of the materials inclosed more effectually, it will, on the contrary, when on the outside, destroy the action of the waves upon the framing to a greater extent. In the latter position also the planking can be more

easily repaired, and no asperities are offered able to affect or be affected by any vessels which may rub against the jetties in passing. It is a very important rule to be observed in all constructions connected with piers or quays, that no essential parts of the framing be exposed to the abrasion of vessels either passing or stationary; wherever there is a possibility of any occurrence of this description, it is advisable to place a firring to protect the permanent work.

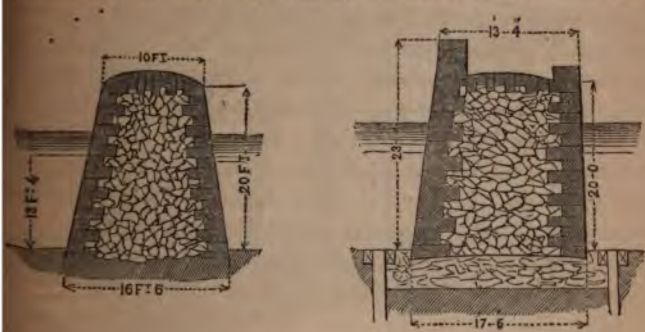
In modern jetties the frames are made distinct from the piles or other portions of the wood-work in or near the ground. There is great difficulty, in fact, in driving with regularity such long piles as would be able to receive the flooring; and it is very easy to place the whole of one of the previously-prepared frames of the upper structure upon its foundations during the interval between two consecutive tides. The supposed advantage to the solidity of the structure in consequence of the posts being identical with the piles, it may also be observed, soon ceases to exist; for in a short time the destruction of the wood from the alternations of dryness and wetness, or from the attacks of the worm, render it necessary to replace portions of the work.

It has been observed that piles driven into the sea-shore are rapidly laid bare by the shock of the waves. The ground-swell acts upon the bed of the sea, and in time produces a conical depression round the head of the pile, whose depth may sometimes become as much as from 2 to 3 feet in a tide. These depressions extend on all sides, so that the piles are often laid bare for a considerable length; and to obviate this danger it is usual either to fill in between the pile-heads with concrete or with stone rubble, or, in Holland, to place a matting of fascines loaded with rubble, through which the piles are subsequently driven.

The advantages offered by wooden jetties may be stated to consist in the fact that they are rapidly and economically constructed; the disadvantages they present consist in the frequency and cost of their repairs, and also that they

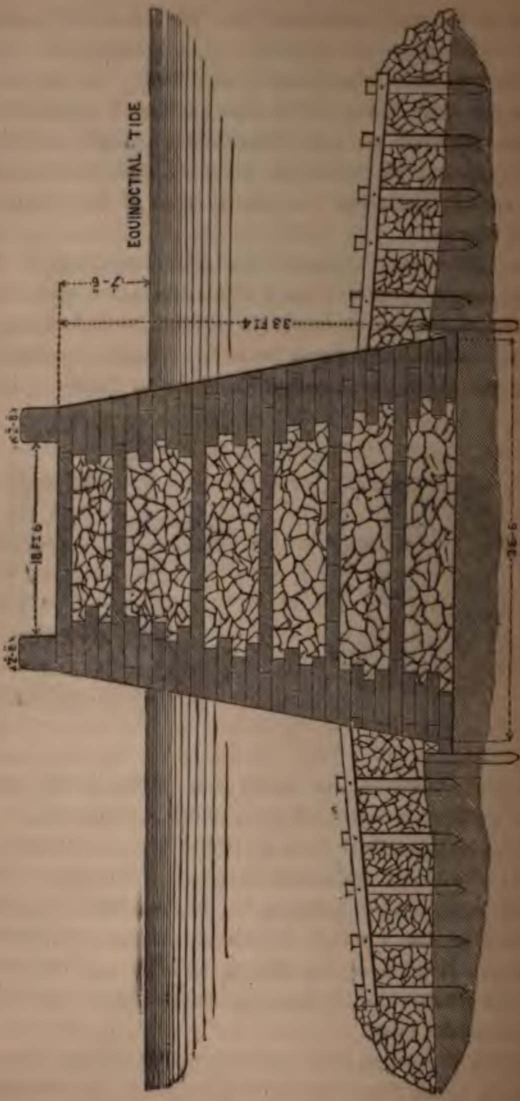
do not effectually guarantee the interior of the harbour from littoral currents if totally or partially open, nor do they destroy the agitation of the waves. It is on this account that in many ports the system of partial filling has been resorted to, and the practice usually followed is, to carry up the filling to the level of high spring-tides in very exposed situations, or only to that of the high neap-tides in others.

Stone jetties are executed either with a hearting of rubble masonry or of concrete cased with ashlar, or with an embankment of earthwork cased by external walls tied together by cross walls, which form, in fact, so many separate compartments; or even occasionally of loose rubble. In the



latter case, however, the inner face towards the passage of the harbour is executed in coursed masonry with a vertical or nearly vertical face, in order not to interfere more than is absolutely necessary with the water-way. Telford adopted innumerable varieties in the methods of bedding and bonding the masonry for these various descriptions of jetties, but there does not appear to exist any necessity for observing other rules in their construction than will be found enumerated hereafter.

In positions where it is easy to obtain large stones of a nature to resist the action of sea water, it is preferable to

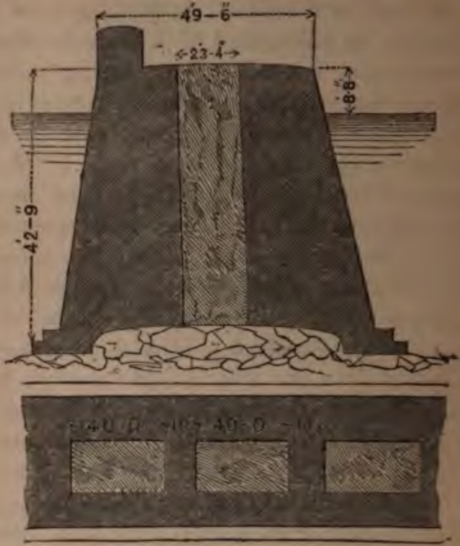

EQUINOCTIAL TIDE
33 FT 4
18 FT 6

xecute jetties with ashlar facings, and, generally speaking, o fill in between them with rubble masonry or concrete. A vertical face, we have already seen, destroys the violence f the waves with greater rapidity and more effectually than long slope, such as every loose rubble jetty must assume, rovided that it be constructed of a sufficient dimension; nd with the requisite conditions of bonding together the everal parts, a wall of such a profile will require less repair han a mere heap of small materials, each of which is usceptible of being displaced in a storm. The largest tones which can be obtained ought to be used, especially at e height corresponding with the greatest agitation of the aves, and for the upper courses: horizontal bonding courses hould be introduced at regular intervals, with plugs or dowels nnecting the several stones, and the upper surface of the fill-g in must be carefully paved so as to throw off any rain or a-water falling upon it. The example given on the oppo-ite page will illustrate the most theoretically perfect mode of xecuting such works; it is copied from the southern jetty of he port of Havre, which is exposed to very violent storms winter, and in all times to a powerful littoral current.

When the interior of the jetty is filled with earthwork, it s necessary to place the counterforts tying the walls together t distances varying from 16 to 45 feet in the clear, making he counterforts from 6 to 10 feet wide. The thickness of he retaining wall must exceed that absolutely required, to nsure a resistance to the thrust of the embankment under rdinary circumstances, because the action of the waves hanges very materially their conditions of stability. The ost important precaution to be taken is to pave the top o as effectually to remove any water falling upon it. The nclination to be given to the walls may vary from 1 in 4 o 1 in 8; perhaps the latter is preferable as a general rule.

In some positions the progress of the shingle is found to xercise an important and very destructive effect upon the iers projecting within its line, in consequence of its friction

upon the stonework. De Cessart recommended that a casing of planks from 3 to 4 inches thick be placed round the portions exposed to this abrasion, and that they should be nailed to horizontal whalings let into the stonework.



If the use of such boarding be objected to, it will be necessary to execute the portion thus rubbed by the shingle in granite, and under any circumstances to avoid the use of soft argillaceous or calcareous stones.

The foundations of jetties should be executed in the most substantial manner possible, and either upon a general bed of concrete, or upon a platform laid upon piles and surrounded by sheet piling; if the subsoil be of a nature easily removed by the repercussion of the waves or the action of the current, it may also be necessary to construct a wide apron, in a similar manner to the one executed at Havre, represented in the fig. at page 98. These aprons are more peculiarly required at the head of the jetties, where the ground-swell

is the greatest; and they should be carried down as low as possible, the upper surface having either a slope or a curvature towards the open sea, so as to decompose the shock of any waves breaking on it.

If the extremity of the pier be carried out far into the sea, so that the foundations be below the lowest tides, it will be found almost impossible to execute them in a cofferdam. The modes hitherto employed under such circumstances have been to construct them of loose rubble-stone up to the low-water mark, as in the cases of the piers at Aberdeen erected by Telford, or of those at Honfleur; or to execute that portion with concrete, or with masonry sunk in caissons.

The loose rubble foundations answer in positions where there is no danger of the substrata on which they repose being removed, and when the passing current carries a sufficient quantity of mud or sand to fill up the interstices of the stones. Works of this description, if executed in tolerably deep water, assume the profile upon a line of direc-

n of the prevailing wind, which may be thus described:— the outside, and in the part situated below the usual ion of the waves, the slope of the materials, as they

arrange themselves naturally, will be tolerably steep, about 1½ to 2. In the zone exposed to the action o waves it becomes about 6 to 11; and the inner slope, w is of course protected by the other, assumes the proporti 1 to 2. The lower slope, or the one beneath the acti the waves, is, however, the only one which has any fixi to speak; and it is also to be observed, that in shallow the ground-swell appears to destroy it even in this po and to give rise to constant changes in the outline. instance, a rubble jetty executed upon a ledge, calle Boyard, in the roads of Aix, on the western shor France, was continually undermined at the foot, althoug foundations were placed at 14 feet below low-water line is therefore necessary to cover the smaller stones, of the body of such jetties is composed, with blocks of siderable dimensions at the feet, and also in the zones ex to the action of the waves. The immediate position intended jetty should also be covered entirely by a l concrete, executed after a sufficient time has been giv allow the subsidence of the rubble to take its full effec the masonry elevated upon this concrete. The sketch preceding page, representing the jetty of Honfleur, mouth of the Seine, will illustrate this construction.

When the foundations are executed in concrete, the nal edges should be protected by sheet piling, and preca must be taken to prevent their being undermined. surface of the place intended to receive the concrete m cleared of any alluvial mud or peat, and as far as po of any compressible substratum. But the most imp condition for ensuring the permanence of this descript work is, that the lime or cement used be of a natur to resist the chemical effects of the sea-water.

Smeaton executed the foundations of the Ramsgate bour in caissons, sunk afterwards upon beds previousl pared to receive them by means of the diving-bell. piers are carried out about 300 feet upon a chalky bott

arying from 8 to 10 feet below low-water mark of les. The caissons were about 10 feet wide, and ong, measured perpendicularly to the axis of the e heavy storms which blow upon this part of the n the S.E. moved the caissons, until they were by the superincumbent masonry.

entirely in loose rubble work ipally constructed for the of destroying the force of , without its being intended hem serve for the purpose g the manœuvres of vessels r departing. Such a mode ction may be advisable when materials are easily pro- d when skilled labour is ex- dear; but, as a general rule, found that the ultimate ex- the maintenance of such ll more than counterba- economy in the original Telford has, however, exe- eral jetties in this manner, an illustration from the rm of the Kingstown Har- elected. In other cases, as head, he made the inner a vertical face of dressed but it is to be remarked, ccasions on which that emi- ineer resorted to this mode uction were decidedly excep- his usual course, and that it was economically pos- execute jetties in coursed he resorted to that system.

In addition to the interference with the trans waves into the interior of harbours offered by the disposition of the jetties, or by the breakwaters b scribed, that object is sometimes effected by means projecting from the inner face of the jetties into bours. This is a system only to be resorted to u ordinary occasions; for, as the spurs project into t line of the channel, vessels entering the harbour m sionally be forced to go through manœuvres atten considerable danger. The practice of engineers, years, has certainly been to avoid any kind of devia the regularity of outline of harbours for this reas submersible jetties, formerly constructed in prolon the principal ones, or more frequently of the leewar have also been abandoned. Indeed it was found tha were covered at high tide, they became little e sunken reefs in the course of vessels entering, rise frequently to serious complications of the t currents of the port.

In the above remarks upon the construction of t or piers at the entry of harbours, it has been assu the roadstead was sufficiently sheltered to allow the f of a port, without the necessity for the executio works in the roads themselves. This, however always the case, and, as was before said, the form a breakwater is sometimes necessary to secure the tr of the roads. Plymouth, Cherbourg, Cette, and th the mouth of the Delaware, have been cited as illu of this species of construction, and they offer differences of *principle* even to require a somewhat examination. A notice of the breakwater of the Buffalo, on Lake Erie, is added, for the purpose of the methods adopted by the American engineers may really be called their fresh-water seas.

The "Digue" of Cherbourg, the first in chro order and in size, is unquestionably one of the

most gigantic works executed by man. Its total length about 4120 yards, and it consists of two arms, respec-ly 2441 and 1679 yards long, forming at their junction obtuse salient angle towards the open sea of about 169°, h an average depth of water, at high spring tides, of ut 62 feet. The foundations for a circular battery,) feet in diameter, have been prepared at the east end, l at the west end, for a similar fort of 134 feet in meter; whilst at the point of junction of the two arms, foundations have been laid for a fort of about 640 feet development. The width of the passes between the remities of the digue and the main land, at the points ere fortifications (crossing their fires with those of the ended forts on the digue) are erected, is respectively 10 and 2515 yards. The area sheltered by this work about equal to 1927 English acres at low tides; but of s, not more than 696 acres have a depth of 27 feet the lowest tides. Of this deep-water surface it also pears that nearly two-thirds are exposed to the unbroken lence of the ocean during the winter months, so that lly the roads of Cherbourg, notwithstanding the immense t of the digue, can hardly be said to be able to shelter re than from 25 to 30 sail of the line, inasmuch as h vessel requires from about 8½ to 10 acres superficial swing freely upon its anchors. In the shallower parts the roads, an equal number of frigates could be made ride in safety.

The original intention in constructing the digue was, that should be submersible at one-third of the rising tide. is intention was subsequently abandoned, and the height s proposed to be at different periods, firstly, that of the linary spring tides, then 10 feet above that line, and finally actual height of 12 feet 6 inches was adopted. The tch No. 1 overleaf will represent the normal section the digue; the sketches Nos. 2, 3, and 4, are introduced show the modifications of the profile superinduced by the

action of the sea between the years 1788 and 1829. As will be seen upon inspection of these figures, the slope

No. 1.

No. 2.

No. 3.

No. 4.

of the seaward face had materially changed; and in 1829 as it was found that the tranquillity of the roads was by

ans secured, and that the small blocks were constantly
over from the sea side to the inner face, it was
ed, after long and anxious deliberation, to crown the top
sea slope with a vertical wall, as shown. The original
was completed to the line of the low spring tides in
blocks, and after the materials thus added had been
d to settle, they were covered with a bed of hydraulic
ete 5 feet thick, and upon this a solid wall of coursed
masonry, the external and internal faces of which were
ted in granite, with rubble hearting, was erected as
. The top of the sea slope is covered with large loose
, and at the extremities of the wings it is further pro-
by immense artificial blocks, of about 40 tons weight
formed of rubble set in Roman or Portland cement.

Baron Cachin's history of this astounding work, and in
l's edition of Sganzin, may be found further details of
ode of construction, and of the accidents which hap-
to the digue, from the year 1786, when De Cessart
his ingenious but unsuccessful system of sinking vast
of masonry, up to the year 1840. Since that period
onstruction of the upright wall has been continued,
t being interrupted by any accident which should lead
nodification of the system. Some serious settlements
aken place, from the unequal compression of the new
work under the enormous pressure of the upper wall;
ossibly also the older portions of the digue may
een similarly disturbed. At any rate, the whole mass
looser ubble has been considerably compressed, for the
s been observed to sink throughout its length about
on the average, the movement taking place with con-
le rapidity the first year, and diminishing gradually
the second and third, whilst it is barely perceptible in
rth. This result ought not, however, to excite sur-
or the stones used in the body of the rubble work
so greatly increased a volume beyond their natural

one whilst in the quarry, that their bulk in the digue before compression is to that they previously occupied as 1·5 to 1. The result of the compression has been to produce in the north and south faces of the vertical wall a series of irregularities and curved lines, both in a horizontal and a vertical direction. The maximum deviation of the former is said to have a chord of about 730 feet, with a versed sine of 17 inches; of the latter, the chord is about 2000 feet, and the versed sine 24 inches; and in some instances the cracks superinduced in the masonry extended to such a degree as to require the demolition of parts of the wall, together with modifications of the heights of the next following courses, in order to secure horizontality in the beds. As the parts which have been subject to these settlements have now for several years resisted the effects of the heaviest storms, they may perhaps be considered not to endanger the solidity of the work; and at all events they must be regarded as inevitably attached to the mode of construction of the body of the digue, viz., of loose stone rubble left to arrange itself.

The breakwater of Plymouth is formed in a bay sheltered on three sides by land rising to a considerable height, and only open to the south. Several banks, or natural reefs of rocks, exist, between which and the shore there were three principal passes towards the east, the west, and in the center. The breakwater is erected upon the banks situated the nearest to the interior of the harbour, and closes the center passage; the banks situated more towards the open sea serve to break the fury of the waves before they arrive upon the breakwater.

The main body of the breakwater is placed perpendicularly to the S.S.E., from which quarter the severest storms assail the Plymouth Roads. The total length is 1700 yards, of which the rectilineal central part occupies 1000 yards, and the two arms, forming on either side angles of about 135° with the center, occupy respectively 350 yards each.

urface of about 1120 acres is, by means of this work, dered available for large vessels.

Originally it was intended to make the width of the top of breakwater only 11 yards, and that of the bottom about yards; but during the execution of the works, the width the top has been increased to 15 yards, and that of the ttom to 133 yards. At the level of the low water at ring tides, a set-off 22 yards in width is formed, and the opes from this point upwards, on the sea side, are paved th large stones, 4 feet by 3 feet 6 inches, by about 3 feet ick, laid with an inclination of 5 base to 1 height and dded in Roman cement; and it is proposed to continue is paving below the lowest water line by means of the iving-bell. The height of the crown of the breakwater is nly 2 feet above the level of high spring tides.

It appears to be beyond question that the long slope of the Plymouth Breakwater is less exposed to be injured by the violent shocks of the sea than the vertical wall of the Cherbourg Digue; but at the same time it is equally beyond question, that the latter destroys far more effectually the agitation and undulation of the open sea, and offers a greater resistance to their transmission into the inner harbour, because the waves in Plymouth Sound during violent storms break over the slopes, whilst at Cherbourg all their effect is destroyed by the wall. In the latter case, however, the descending motion of the return wave is materially interfered with. The vertical wall at the top of the long slope transforms it, in fact, into a horizontal motion, whose velocity is highly dangerous to the stability of the foundation of the wall. It is also found that the large blocks of stone detached from the outer slopes are driven against the outer face of the wall with extraordinary violence during great storms, whilst upon the long paved face of the Plymouth Breakwater the waves, not meeting with any abrupt resistance, break in precisely the same manner upon the incline that they would do upon a natural shore, and with a considerably diminished degree of

violence. It is true that, in consequence of this form, they acquire an increased horizontal velocity in their original direction; but as the top of the slope is rendered as smooth as possible, there are no salient points in the masonry able to attract, as it were, the destructive action of the waves. Notwithstanding the precautions observed in the execution of the top slope of the breakwater, it is by no means of rare occurrence that blocks weighing from 2 to 5 tons are carried over from the sea to the land side; and in February, 1848, considerable damage was caused to the upper parts.

A lighthouse is proposed to be erected at each extremity of the breakwater; but only one has been completed.

The breakwater in Delaware Bay was designed not only to form an artificial roadstead sheltered from the effects of the prevailing winds, but also from the drift ice brought down occasionally in large quantities from the upper parts of the Schuylkill and Delaware Rivers. It was also contemplated that the port thus created would rather be a place of refuge for ships bound coastwise, than it would become a touching port for vessels dropping down the river. In consequence of these local circumstances, the works for the shelter of the roads consist of a breakwater and what may be called an ice-break. The breakwater itself is in a straight line, in a direction W.N.W. to E.S.E., and of a total length of 1000 yards measured upon the line of high water, leaving a channel of about 1000 yards in width between its E.S.E. extremity and the main land. At a distance of 555 yards from the W.N.W. extremity, the prolongation of the line of the inner slope of the breakwater meets the line of the inner slope of the ice-break, forming with it an angle, towards the shore, of 146° 15′. From the point of intersection, the line of the ice-break is carried respectively 272 yards W. by S., and 228 yards E. by N., making a total length of about 500 yards, with a clear passage of 350 yards between it and the main breakwater.

The space thus sheltered has an area of about $\frac{1}{8}$th of a mile so

r as the waves raised by winds from the N.W to the E., pass-g by the N., are concerned; and a space of $\frac{1}{25}$ths of a square ile so far as those caused by winds from the N.W. to the E. y the N.) are concerned; and in both cases the minimum epth so sheltered is 24 feet. The area of sheltered road, with minimum depth of 18 feet, is about $\frac{7}{10}$ths of a square mile. he tides in this locality are but feeble, for the average ange of the neap tides is about 4 feet 8 inches, and that f the equinoctial spring tides about 7 feet 6 inches; whilst he greatest range that has been noticed has never exceeded feet 10 inches vertical.

The transverse section of the breakwater was made as fol-ows:—The inner slope, towards the harbour, was formed at n angle of 45° with the horizon; the top was made 30 feet

ide, and at 5 feet 4 inches above the level of the highest pring tides. The outer slope was carried down, with an nclination of 3 base to 1 in height, to a depth of about 9 feet from the highest spring tides, and from thence to the ottom, at an angle of 45°. The mass of the work between he sea bottom and a horizontal plane passing at 6 feet below he lowest spring tides, was formed of stones weighing from to 2 tons, and the slopes covered with blocks of from 2 to 3 tons minimum weight. Between this point and the plane corresponding with the lowest spring tides, the body of the work was executed in stones weighing from $\frac{1}{2}$ to $2\frac{1}{2}$ tons, protected externally by blocks weighing 3 tons each at least; and the upper portion was formed exclusively of blocks weighing from 4 to 5 tons, laid as regularly as possible, the slopes being covered with the largest blocks, laid as headers.

The breakwater of Cette is principally remarkable on

account of the great height to which it is carried above the highest water line; this is not less than 19 feet. A section of its normal profile has already been given at page 53: the total length is about 514 yards, and the outline on plan is convex towards the open sea. During its execution, observations were made from which it may be inferred that the constant undermining of the sand upon which this breakwater was constructed, so long, at least, as the transverse profile was made very steep towards the open sea, would indicate a danger of superinducing a ground-swell highly injurious to the permanent solidity of the works, unless the sea slope, in similar cases, were carried out at once to the full width. It is also seriously questioned by the pilots resorting to this harbour, whether the breakwater does not materially assist the natural tendency to silt up which so strongly marks this and several other ports of the Mediterranean.

The breakwater upon Lake Erie, at the entrance of the port of Buffalo, in the State of New York, is con-

structed with nearly as much solidity as similar works upon the shores of the ocean. Its length is 484 yards in a straight line; the platform at the level of the first set-off is 18 feet wide, and 5 feet above the water-line in the interior. A wall 5 feet high is carried up above this platform, and beyond this a gentle slope of about 3 base to 1 in height is carried down to the bottom of the lake. Towards the port the face of the breakwater is perpendicular, and it is defended from being injured by vessels lying alongside it by guard-piles driven in every 5 feet apart. A row of sheeting piles is driven upon the external edge to protect it from the effects of the ground-

ell; the mass of the breakwater is executed in loose rubble asonry.

In addition to what has already been said with respect to he precautions requisite to be observed in the construction f piers and breakwaters, it is important that the lower ourses of the masonry be covered by the succeeding courses s rapidly as possible, not only to enable them to resist the irect action of the waves, but also the syphonic action of the water driven into the joints. For the latter reason also it is mportant that the joints between the stones be executed with the most energetic cements, and be made to fit very losely. If the hearting be executed with small stones, the nequality between its rate and degree of compression is ikely to give rise to hollow chambers, which facilitate this syphonic action; and it appears therefore indispensable to introduce a greater or less number of horizontal bond courses, according to the nature of the materials employed.

Experience also appears to show that it is safer to raise the masonry, in such positions, to its full height partially at once, rather than to endeavour to carry it up regularly throughout the whole length, in order that the superincumbent weight of the upper courses may assist in maintaining the lower ones in their places. This precaution is peculiarly necessary when the walls have reached the mean level of the sea, at which point the waves act with the greatest effect. In solid masonry in these positions, the rapid setting of the cements or mortars is a condition of vital importance; and it is also necessary that only such materials of either of these classes be employed, as allow of being prepared for use with salt or resh water indifferently.

Beyond the jetties, in all seaports of importance, it is usual o construct an outer harbour, surrounded by quays, at the ottom of which are placed the docks intended *to receive* essels of large tonnage, and *to retain the water entering at* igh tide, *so as to allow* the operation of unloading to be per-*formed whilst the vessels are afloat.* Small vessels and

ing craft generally remain in the outer harbour, as do also the coasters or other craft able to depart at half tide. The sluice-gates, and the leading channels from the back-water, whether it be natural or artificial, are also placed upon some portion of the outer harbour.

The length to be given to this part of a port will depend very much upon the facilities it may possess, with respect to the entrance or departure of vessels. It frequently happens that during windy weather these may retain a very considerable portion of the momentum derived from the velocity they had whilst under sail; sufficient space must therefore be allowed for the destruction of this momentum before the vessels arrive at the locks giving access to the inner harbour. On this account, also, it is preferable to direct the entrance between the jetties a little out of the line of the prevailing winds, and to place the lock-gates somewhat out of the direct path followed by the vessels entering. Generally speaking, it will be found sufficient to make the length of the outer harbour about 700 yards.

The quay walls of a harbour are required to fulfil the same conditions as the walls of river wharfs, that is to say, to resist the lateral thrust of the ground, and to facilitate the discharge of vessels. For the attainment of the latter condition, it is important that they be as nearly vertical as possible; but in proportion as this object is attained, the stability of the wall itself is diminished. The late Mr. Rennie, and after him the majority of English engineers, endeavoured to reconcile the two conditions by building their quay walls with a curvilinear batter on both sides, laying the courses normally to the curve. By this means the stability of the wall for the same cubical quantity of masonry is certainly increased, and the face stones —being, in fact, voussoirs—connect the masonry intimately throughout. At the same time the mechanical difficulty of execution is greater than in a wall with horizontal masonry, and this mode of construction entails the necessity of using inclined piles, which should be avoided as much as

le. The Dutch engineers occasionally incline the two of the wall in a direction parallel one to the other, and it they overhang on the inner side at the top. The ing joints in such cases are dispensed with; but the ty of such walls, especially when constructed upon soft is never satisfactory, for the overhanging portion of the

Fig. 1.

Fig. 2.

masonry adds to the lateral thrust of the earth upon that portion of the foundations and wall below the center of gravity. Walls of this description may almost always be noticed to have yielded at the feet. In the French ports upon the Channel it is customary to build the walls nearly vertical in the manner represented in fig. 2., which is taken from uay wall of the outer harbour at Havre. The mean ness adopted in these ports is not less than 0·40 of the

total height considered as unity, and, strange as it may appear to our ideas upon the subject, it is found practically that this great thickness is not sufficient to ensure the stability of the walls in many cases, for many of them have yielded.

The rounded outline of the bottom of ships admits of the formation of a set-off, or of an apron, to protect the foundations. In the case of the docks at Antwerp, as the rock in which they were excavated was sufficiently solid to dispense with the necessity of a facing of masonry, the set-off was formed in the rock itself. This is, however, a course of proceeding which should only be resorted to when there can be no danger of the undermining of the walls.

The thickness to be given to the quay walls, and the precise mode of construction to be adopted, must evidently, from what has been said above, depend upon local considerations of the cost of materials and of labour. The most important theoretical consideration affecting them is to be found in the fact that the earth behind them is exposed to be alternately wet and dry twice a day, and that the capillary action of the ground causes this action to rise to a greater height than the limits of the tidal range. The earth in this condition must be considered to be a semifluid mass assuming naturally a slope forming an acute angle with the horizontal line. But the most serious difficulty attending the construction of the quay walls of ports arises from the yielding of the mud under the foundations. If the mud lie upon a solid substratum which can be reached by piles, it is possible to found the wall in such a manner as to guarantee it from any danger arising exclusively from the vertical pressure. But it frequently happens that the mud moves laterally under the compression of the earthwork behind the walls, driving out their foundations, and forcing up the bed of the harbour. Accidents of this description occurred at Southampton, Lorient, and Rochefort; and it appears that if the stratum of mud be of great thickness, the only effectual mode of combating the danger is to lighten the vertical pressure of the filling behind the walls by means

f fascines, timber platforms, or by hollow vaulting. The uay at Lorient is erected upon a bed of mud of unfathom-ble depth, and in this case both the wall and the platform ehind it are carried upon piles driven with the broad end ownwards.

Guard piles ought to be placed in front of quay walls to rotect them from the abrasion of the vessels moored along-ide as they rise and fall with the tide, or from the shocks f vessels driven against the walls, occasionally with consi-erable violence. These piles need not descend below low-water mark of neap tides: they are usually bolted to the asonry, and covered with an iron cap. In the angles of arbours, staircases or inclined roads may be placed, to assist n unloading small boats. The only important precautions o be observed in their formation are, that all external arrises e rounded off, and every description of projection likely to jure the bottoms of vessels studiously avoided. The same emarks apply to all ladders mooring rings, or other facilities r the manœuvres of the port.

The dimensions and dispositions of the inner harbour will be gulated by the nature of the vessels frequenting it, and the epth must be such as at all times to exceed the draught of ater of the largest vessel it is likely to receive. This excess f depth is required, firstly, to compensate for any loss of water hich may take place between two consecutive tides, whether arise from evaporation or leakage; secondly, to allow of the bstraction of a certain quantity of water for the purpose of couring the passage in front of the lock-gates; thirdly, to revent the possibility of the vessels grounding, should any gitation either be transmitted from the outer harbour, or e produced in any manner in the inner one; fourthly, to llow of the gates being opened a little before the period of he highest tide so as to permit vessels of light draught to eave at an early period; and fifthly, to provide against the radual silting up of the inner harbour. In order to provide gainst all these sources of possible annoyance, and to secure

the eventual advantages, it is usual to make the depth of inner harbours from 2 to 3 feet in excess of what is absolutely required to receive the vessels frequenting it.

As an economical question, we may consider that the dimensions of length and breadth should be decided upon the principle that the greatest number of vessels should be able to lie alongside the quays, with the smallest amount of expense in the excavation of the water surface. At the same time, it is necessary to leave between the different tiers of vessels a space sufficient for the evolutions of those about to enter or depart. In some of the most convenient modern ports, intended to received commercial vessels only, the length is made about five times the width, and in these instances vessels often lie in three tiers on either side. In military ports, however, it is necessary to bring every vessel close to the quay, and therefore the proportionate length may be less than that above stated. At Cherbourg, where the expense of excavating the basins in the solid rock was enormous, their dimensions were reduced to the minimum; one of them was therefore made nearly square, or 754 feet wide by 852 feet long; whilst the second was made 656 feet wide by 1312 feet long, or in the proportion of 1 in width to 2 in length.

The gates closing the inner harbour should be constructed with a view to secure the most rapid operations in opening and shutting, and to render the leakage at the several joints as small as possible. Their width must be regulated by the class of vessels entering. Barques and sailing vessels under 500 tons burthen do not require a greater width than 50 feet; a first-class frigate does not require more than 52 feet; nor does a first-class sail of the line require more than 60 feet. But the colossal dimensions of some of the modern steamers renders it necessary to make the gates through which they are to pass not less than from 70 to 80 feet wide. It is customary to place sluices at the bottom of the lock-gates to assist in scouring the platform at the entry.

The depth of the floor of the passage will be regulated by

draught of water of the vessels entering. A 500-ton sel will draw about 16 feet, a first-class frigate about 22 , and a first-class man of war about 27 feet, supposing m to be under full load. As the draught of steam-boats is nowise commensurate with their width, they may be conred to be comprised within these dimensions.

Unless there be very great inequalities of tide, one set of es will be sufficient to retain the water during the period he ebb; but it frequently happens that it is indispensable place a set of gates to exclude the flood-tide, especially en repairs are likely to be required to the flooring of the e passage, or the inner harbour. It appears, therefore, a y necessary precaution, to construct the chamber and pase so as to admit of placing two pairs of gates, respectively provide against the ebb and the flood tides; and in many nmercial ports it may even be advisable to place a second r of ebb gates in order to allow the intermediate space to ome a species of lock to facilitate the departure of small ft at the half tides. A provision should also be made for insertion of a coffer-dam; and in almost all cases it will necessary to construct a turning bridge for the purpose of necting the roads or quays on either side of the passage. the side walls of the lock chambers it is also customary construct culverts, provided with gates and raising manery, for the purpose of assisting the scouring action of sluices in the gates themselves upon the passage leading to the latter. It follows, therefore, from the necessity for se several works, that the length to be given to the entrance m the outer to the inner harbours of any port must vary ording to the local conditions of tide, or of the communiions between the two banks of the innner harbour.

Although, as was previously observed, the effect of sluices in many cases merely to transpose the deposits of shingle sand from the points directly within their influence to ers where, perhaps, they may be somewhat less injurious,

yet it is possible to obtain by their means such remark
advantages, that it is necessary to dwell shortly upon
consideration, especially as the real value of this cla
works is but little understood. The best form to be g
to an artificial backwater retained for this purpose would
sector of a circle, but with a chord line, towards the ou

formed by a portion of
development of a circle
greater radius than that of
inner contour; the gates b
placed as nearly as possibl
the line of the centers.
degree of efficiency of their action depends upon
volume of water they can contain, and the velocity with w
this may be allowed to escape without injuring the foundat
of the jetties or other works it may encounter. So lon
the stream escaping from them is confined in such a ma
as to act entirely upon the channel, it is possible to obtai
increase of depth, which in the immediate neighbour
of the sluice may attain as much as 8 feet. In proport
however, as the stream escaping loses its velocity, its po
of transporting the materials previously detached beco
diminished; so that it is by no means rare to observe
the shingle or silt removed near the sluice is again depos
nearer the mouth of the harbour; and in almost every insta
the meeting of the scouring stream with the littoral curr
should any such exist, gives rise to a bank at a distance f
the extremity of the surface guiding the water from the slu
depending upon the velocities of the latter and of the litt
current. It is therefore of vital importance that the velo
of the water at the moment of its leaving the sluices b
great as possible; that its path should be free from any
structions likely to retard its flow; and that the distanc
the sluices from the head of the piers be such as to allow
water leaving them to retain its velocity for some time

falls into the sea. It is also necessary that the direction of the outflowing stream correspond with that of the shingle or silt brought in by the returning tides.

Upon the various ports of the British Channel, especially upon those of the French, Belgian, and Dutch shores, many works of this description have been executed; and it appears from an examination of the results there obtained, that a velocity of about 5 feet 6 inches per second, immediately beyond the eddy produced near the sluices, is desirable in such cases as those in which the bottom of the harbour consists of small shingle. The distance of the most efficacious of these sluices from the extremities of the jetties does not exceed 900 yards; although, when the materials brought in by the tide consist of a sandy mud, there does not appear to be any serious inconvenience in making this distance 1000 yards. The cubical capacity of the sluice must be sufficient to ensure the flow of the sluicing stream for a period rather in excess of that required to remove the materials brought into the harbour during the intervals of the tides. It may be obtained either by retaining the water flowing in from the sea itself, or by upholding the land waters for periods sufficiently long to secure the quantity required, or by a combination of these sources.

In practice, the openings of the sluice gates vary from 7 to 20 feet in width, and the intermediate piers are made from 10 to 11 feet in width. Large gates are advantageous in this respect, that they interfere less with the discharge of the water than smaller ones would do; but at the same time their execution is more costly, they are more likely to get out of repair, and their maintenance, and also their ordinary working, is more difficult. The most important consideration affecting their construction is, however, more especially connected with the floor which must not only be capable of resisting the transporting power of the escaping water, but also of resisting the hydrostatical pressure of that which is retained in the inner basin. In many instances it has been deemed advisable

to make the total length of the floor not less than 120 feet, in order to obviate any danger of these causes affecting the stability of the sluices.

But it must always be borne in mind, whilst considering the expediency of these additions to the efficient working of harbours, that their first cost is usually very great, and their maintenance very expensive, whilst at the same time the effects they produce are only of a questionable character. Should the materials brought into a port be of a sandy or silty nature, it will almost always be found more economical to remove them by dredging; and, in many cases, the same remark will hold good with gravel or shingle. But, if a tidal current can be made to pass with considerable velocity along the passage leading to the inner harbour, or if, in fact, any natural back-water exist which can be directed so as to act efficiently for sluicing, without entailing any serious outlay, it is highly desirable that it should be made use of. Local circumstances must eventually decide this, as they must all other questions of detail.

A very important branch of the science of hydraulic engineering, as applied to the construction of sea works, is that connected with the chemical action of the salt water upon materials immersed in it, and the peculiar ravages some of these are exposed to from members of the animal kingdom.

Some stones and mortars, not only when immersed, but also when exposed to the sea air, may often be noticed to decompose and to become covered by an efflorescence of the carbonate of soda, resulting from the action of the hydrochloride of soda in suspension in the atmosphere, or in combination with the water, upon the carbonate of lime. The hydrochlorides of magnesia present in sea-water act in a very peculiar manner upon some stones and mortars; for when the former exist in the state of protocarbonates of lime, the magnesia enters into combination with it, and as during that process a new crystalline arrangement takes place, it

s frequently the case that the stone disintegrates. With the rgillo-calcareous stones, however, this action does not take lace, and it would thus appear that the combination of the ime with the alumina is sufficiently energetic to enable the tones in which that state prevails to resist the decomposition f the sea-water. The same remarks apply to mortars and ements; for it is found that unless the mortars made with rdinary limes are perfectly carbonized before being immersed, r unless the cements be obtained from natural argillo-cal-areous rocks, or, if artificial, unless the lime and alumina ave been made to combine intimately by the effects of usion, however well they may appear to resist in the com-nencement, they will eventually be certain to disintegrate. At Algiers, Brest, Cherbourg, and the Ile de Rhé, some mortars were employed for the formation of large blocks of concrete, and were composed of moderately hydraulic limes mixed with artificial puozzalanos, prepared, in accordance with Vicat's suggestion, merely by exposing clays to a low heat in such a manner as to allow free access of air to all the parts in incandescence. The concretes thus made resisted satisfactorily for some time, but at the expiration of two or three years they fell to powder; whilst in all cases where the natural puozzalanos have been employed they have not yielded. It appears, therefore, that there are certain changes produced in the alumina by the action of intense heat which render it more capable of combining with lime; and it is probably in this manner that we may account for the ad-mirable results obtained by the application of the Portland cement.

Particular stones, however hard and polished they may be, and in spite of the incessant action of the waves, become rapidly and almost entirely covered with shells and sea-weed, in certain positions, whilst in others they are left bare. This also is true with respect to some mortars; for blocks of con-crete, which have only been immersed for ten days, have been noticed to be covered with marine plants. The boring mol-

lusca frequently attack the softer limestones, with sufficient rapidity to render it necessary to exercise great caution in the choice of the materials employed within the range of their destructive energies. Granites and silicious sandstones are free from their attacks, and some descriptions of limestones enjoy the same immunities; but the precise nature of the latter class of stones is not known with any tolerable degree of certainty. The animals exercising this action upon stones are of the tribe of the *Lithodomi*, or more frequently, in our seas, of the *Saxicava rugosa* and the *Pholas*, the latter attacking principally the chalk, or other pure and soft carbonates of lime.

Iron, whether in the water, or only exposed to its vapours, corrodes with great rapidity; wrought iron decaying, as might be expected, more rapidly than the cast metal. Painting or galvanizing does not appear to retard the destructive chemical action of the salt water materially, in whatever state the iron may be; but there would appear to be a specific difference in the nature of the action upon the cast from that upon the wrought iron, for it is found that the latter becomes simply oxidated to a greater or less depth, whilst the former, after an immersion for about 30 years, becomes converted so thoroughly into a carburet of iron, closely resembling the plumbago of commerce, that it may be easily cut with a knife. De Cessart mentions that, in removing some works executed by Vauban a century previously, he found that in many instances the wrought-iron bolts were intact, whilst other bolts, inserted in precisely analogous positions at a subsequent period, had corroded within a very few years. There would, therefore, appear to be some peculiar states of the iron as employed in the arts which modify its powers of resistance to the chemical action of the salt water. The greatest practical inconveniences attached to the chemical action of the sea-water upon iron are, firstly, *that its* powers of resistance are diminished; and, secondly, *that as its* bulk diminishes also, especially when oxidation

es place, the play thus superinduced upon the framing it ntended to strengthen becomes very great.

Copper and gun-metal oxidate in salt water to a very ignificant depth; but they do not appear to be otherwise ected, nor do they lose their powers of resistance. If, by ans of any description of paint, or of other preservatives, oxidation of the exposed surfaces be prevented, these tals are frequently found to be covered with shells or rine plants.

The most important observation to be made with respect to employment of metals in sea-water is, that under no cumstances should any two different kinds be employed in tact with one another. In such cases a galvanic action es place by the intervention of the salt water, which duces very rapid and important chemical decomposition.

If wood be kept constantly under water it is found that it l last for an indefinite period, and that in the parts left ernately wet and dry, a collection of marine plants and ells, especially muscles, is rapidly formed. The principal nger to which wood is exposed in our seas is, however, that used by the ravages of a species of worm called the *Teredo valis.* It is said that this worm is a native of India, and at it was introduced to Holland some 200 years since, from ence it has spread through the ports of northern Europe. s the fossil wood of the Isle of Sheppey is frequently bored these worms, whose casts are preserved in the fossil ate equally with the wood itself, it may fairly be questioned hether the above story can account for the existence of these sts. Be this as it may, it is not the less the case that the redo bores into the heart of the wood, and destroys the rongest carpentry with frightful rapidity. Thus at Dunkirk ooden jetties are so speedily eaten away that they require enewal every twelve or fifteen years; at Havre a stockade as entirely destroyed in six months; at Lorient wood only sts about three years in the sea-water; and at Aix the hull f *a stranded vessel* was found to have lost half its weight in

six months, from the ravages of these animals. On our own coasts the same destruction is caused by this apparently insignificant enemy; at Southampton, Ryde, Brighton, Dover, &c., the teredo has destroyed jetties with equal rapidity to that observed on the French coast, as above cited.

When the teredo enters a piece of wood it is so small as not to leave any perceptible trace of the passage by which it entered; subsequently it increases until the bore of the passage it occupies is equal in volume to the little finger. It only attacks the interior of the wood it enters, and oftentimes the latter will break off before any external indication is given of the presence of the worm. In piles, or other works in the sea, the zone most affected is that immediately below the main level of the sea; occasionally the teredos extend their ravages below the line of low water of the equinoctial tides, but they rarely mount higher than the line of high tide at neaps. It is believed that they cannot exist under mud so compact as to exclude air; and there are some local irregularities in their distribution hitherto unaccounted for; that is to say, they are often found in some parts of a roadstead or harbour, and not in others.

Engineers have endeavoured to prevent the ravages of these creatures upon jetties or fascine banks, by either covering them with nails or by sheeting them with copper, by coating them with verdigris or cement, or by impregnating the wood with some saline solution. Of these methods, that of covering the exposed surface of the wood with nails, about ½ inch square at the head, appears to answer the best; but in spite of all the care and attention with which it may be performed, its successful results are always problematical. Mr. Hartley, of Liverpool, asserts that the green heart wood of Demerara is not subject to the attacks of the teredo, and the Sabicu wood, from the same colony, is said to possess the same property; but these are the only known exceptions to the rule. All other woods—oak, teak, fir, elm, alike—whether hard or soft, yield rapidly.

There are also other small worms, which do not attack the heart of the wood, like the teredo, until, at least, they have destroyed all the outer parts. Their ravages are, to a certain extent, combated by covering the outside of the wood by thin slabs of the same description, which are removed as soon as they are eaten, and replaced by others.

The details connected with the construction of lock-gates for harbours, and of the various sluices, do not differ in principle from those previously described in Part II., page 70, and subsequently, of this Treatise; nor do they involve other considerations connected with the pressure of the water than those contained in the sketch of the science of Hydrostatics as applied to this branch of special construction in Part III. The facilities to be provided for unloading, such as cranes, &c., will also be found by referring to the chapter on Docks, in Part II; the lighting of harbours is a detail connected with the subject of Lighthouses.

CHAPTER VII.

IMPROVEMENT OF RIVERS.

The precise order traced in the synopsis, for the examination of the general principles of this branch of Civil Engineering, has been departed from a little, for the purpose of keeping the greatest number of phenomena connected with the tidal action before the reader at the same time. But it will be necessary to repeat occasionally some portions of the preceding chapter in order to explain fully the causes and effects of the modifications produced upon rivers by natural and artificial means, or to trace the laws which regulate their flow and influence the outline of their beds.

Rivers are, in fact, the channels by means of which the water originally evaporated from the sea, and falling upon the land, is returned to the parent source. In almost all cases it

is found that towards the interior of a country the ground rises into mountain ridges of variable elevations, and a geological investigation of the successive strata met with in the passage from the sea to the summit of these ridges, generally speaking, shows that the latter are composed of more ancient strata than those nearer the shore. The water falling upon the loftier hills either flows off rapidly, if the rocks be of an impermeable nature, or it is partially absorbed, to be again given out in accordance with the ordinary laws of hydrodynamics; or, becoming frozen at the highest points of the ranges, it gives forth, upon the limits of congelation, streams of considerable constancy of volume. In many mountainous districts lakes are frequently to be found which feed rivers, discharging, in this secondary manner, the waters conducted into the lake by the numerous smaller affluents. In some cases rivers rise in plains, and are fed simply by springs given forth by loftier ranges of permeable strata surrounding the plains. But the largest rivers, and those which are the most constant in their volume, are derived from the mountain ridges, situated above the line of constant ice, rising from wide tracts of table-land.

It may be stated generally, that the superficial configuration of the globe presents a series of such ridges and valleys, either of a simple or a complicated character; that is to say, any particular district consists either of only one system of hills, or of a principal and of several subsidiary chains, which again may either be parallel, perpendicular, or oblique to the principal ridge. The subsidiary chains are accompanied by subsidiary valleys, and the elevations of both decrease in proportion as they become more and more removed from the dominant ridge. It is to be observed, that the secondary valleys, especially when they are perpendicular to the direction of the main valleys, present much steeper profiles, both longitudinally and transversely, than these do; and the several *valleys* thus formed present at their lowest depressions a *channel* into which the waters draining from the surface of the

igh lands, or those released by laying bare the edges of any vater-bearing strata, pour from all sides; the volume of the stream thus collected depends upon the length of the valleys, the nature of the materials they intersect, and the more or less equal distribution of rain upon the upper lands. The existence of dense forests, or other circumstances able to retard the evaporation, have also great influence upon the constancy and volume of rivers.

Rivers present in the whole of their course, from the point where they rise to that in which they fall into the sea or some other river, the following circumstances:—their width ncreases as they advance, and their longitudinal section, xcepting in some extraordinary cases, consists of concave urves, both at the bottom of the beds and at the surface line, lthough these curves are not necessarily concentric or arallel to one another. The courses of all rivers are so evious that it is an invariable rule that their length, mea-ured upon their longitudinal profile, is greater than the ectilinear distance between their extremities. If the river ll into a sea, or another river, whose levels are exposed to ariations, whether periodic or not, the transverse and longi-udinal sections of the one thus falling in are exposed to ariations beyond the influence of their own waters. Should he variations of the receiving channels be subject to tidal ction, the subsidiary rivers will follow the usual laws; the eaps and the springs, the ebbs and the floods, will act upon hem in an analogous manner, but in a different degree, to vhat they do on the sea.

In almost every instance the great mountain ridges are omposed of the granitic or other primary rocks, rising hrough and upheaving the more recent sedimentary deposits. Owing to some law not hitherto explained, the principal axes of the ridges do not occur in the center of the continents or arge islands, but they are always found to be nearer to one of the bounding shores than the one opposed. It follows that the *general inclination* of the land from the ridge towards the

sea differs on either side, and that in one case a long and gradually inclined slope follows the mountainous region, whilst in the other the slope is narrower and more rapid. Illustrations of these laws may be found in all quarters of the globe; it may suffice to cite at present the general disposition of the European continent, which falls away gradually towards the north from the great range formed by the Balkan, Carpathian Alps, and Pyrenees, whose main general direction runs from east to west; whilst towards the south the rate of fall towards the Mediterranean is considerably greater. But it is not to be supposed that although the main lines of elevation of a large geographical district are marked by great regularity, the direction of the flow of its rivers is equally constant. It often happens that subsidiary mountain chains are thrown up in directions parallel to those of the main ridge, and under those circumstances the rivers may be compelled to flow between them in a direction transversal to the normal inclination of the district. Thus, the Danube and the Mississippi both run in directions parallel to the ridges, or back bones, as they are rather appropriately called, of their continents; whilst the greater number of the watercourses, and the general inclination of the respective continents, follow directions precisely opposed.

As the land falls away from the central ridges the rate of inclination diminishes, and in following the downward course of the large rivers the fact previously mentioned may be observed, namely, that the more recent strata are gradually found to occupy the surface, and, as a general rule, their power of resistance to the transporting power of water diminishes in the same order. The longitudinal profile which naturally follows from this law assumes a concave parabolic curve, whose apex is situated at the point of origin, and the velocity of the flow of the river decreases in proportion as it approaches the sea. In the more elevated districts the transporting power of the water is therefore greater, but

the rocks of which they are composed are of a much more sisting nature, the effect it is able to produce in degrading e surface is, comparatively speaking, less than in the flatter stricts near the outfall. Upon the primary rocks, then, we id that rivers have a very imperceptible action upon the itline of their beds, and that the materials they carry down e but little comminuted. Yet in floods, the blocks and agments detached from the escarpments around the water-urses are sometimes carried forward, and broken and unded by attrition during their progress; the distance to hich they are carried varying with their volume and specific avity, as well as with the volume of the river. Following main valley we thus find that at a short distance from its igin nothing but large angular blocks are to be met with; iccessively the blocks become smaller and more rounded; iey then become merely pebbles or gravel, and at length othing but sand or silt.

In the large plains of the more yielding strata, rivers work r themselves beds, whose dimensions are more in accordance ith the tenacity of the soil and the volume of water they arry. If the soil be of a degree of resistance unable to ipport the action of the stream, the banks of the river will ield, and both the depth and the width will increase should iose dimensions not be sufficient to ensure the discharge of ie water. On the contrary, should they be already in xcess, the width will be diminished by the deposition of the iaterials brought down by the floods. The geological, and, o a certain extent, also the mechanical, nature of the forma-ions traversed affect the volume of the rivers flowing through hem, by the greater or less facility with which they part with he rain-water falling upon them. Such rocks as the granites nd compact limestones, especially the lias, allow it to escape lmost as rapidly as it falls; the rivers passing over them nust, therefore, be variable in volume, and if supplied by a arge watershed, frequently of a torrential character. The enser clays, such as the Oxford or the London clays, part

with the water falling upon them rather more slowly than do the class of rocks last mentioned; but the oolites, and the loose open sands, absorb the rain as it falls, and yield it again to the watercourses with great regularity.

Dubuat ascertained by direct experiment the ratios of the volumes of different materials transported by running water with different rates of flow. Thus, he found that

			ft.	in.
Clay, fit for pottery, was removed by water having a velocity per second of			0	3¼
Fine sand . ditto . . .	ditto .	. ditto .	0	6½
Gravel, about the size of peas . .	ditto .	. ditto .	0	7½
Ditto . ditto . beans . .	ditto .	. ditto .	1	0¾
Shingle, about 1 inch diameter . .	ditto .	. ditto .	2	1½
Flints, about the size of a hen's egg .	ditto .	. ditto .	3	4
Broken stones	ditto .	. ditto .	4	0
Soft rocks begin to yield with a velocity of .	. . .	ditto .	4	4
Rocks, with distinct stratification .	ditto .	. ditto .	6	0
Hard compact rock	ditto .	. ditto .	10	0

Very moderate velocities, it thus appears, are sufficient to remove the materials usually found near the outfall of rivers and in large flat plains. The destructive action of the water is also increased by its chemical action in decomposing the materials exposed to it, by the beating of the waves, by the abrasion of floating ice, by the alternations of dryness and humidity, and, above all, by frost. Aquatic plants serve to defend the beds of rivers, provided the depth of water be not very great.

In all large valleys there may be observed traces of a previous geological action of rivers very different from that which they exercise at the present day, in degree at least. The soil, in such positions, consists of alternate layers of sand, clay, peat, and rounded pebbles, whose dimension diminishes as we proceed from the source, and which often are entirely wanting at the embouchure of the river. Through these layers, often of great thickness, the rivers run in channels of a dimension frequently much in excess of those

hey would themselves be able to form. In the valleys of uch rivers as the Rhine and the Seine, particularly, it ppears that, at a period comparatively speaking recent, the urface of the country must have presented a series of lakes ommunicating with one another, like the vast chain in North merica, and in these lakes the materials brought down by he floods must have accumulated. By some violent change hese lakes appear to have been destroyed, perhaps by the radual recession of their lower barrier, in a manner similar that in which the barrier separating the Lakes Erie and ntario is disappearing under the abrasion of the Falls of iagara. But, however this may be, it is certain that the resent volume of the European rivers is not sufficient to ccount for the immense deposits of diluvial matter through hich they flow. And, in many cases, it is equally certain hat the materials they now transport in the lower part of heir course are derived from the previous accumulations of iluvium, rather than from the ridges from which they derive heir supplies of water; and that these rivers now carry orward silt and mud much more frequently than they carry ravel of any considerable volume.

The manner in which rivers fill up, or raise, their beds, is subject involved in some obscurity, or at least it depends pon causes which are often purely local. In many rivers he tendency of the water is rather to lower the bed, especially when it runs upon hard rocks, than to deposit the etritus brought down from the upper districts; and this endency to deepen the beds is principally confined to the pper and more rapid portions of the course. The detritus n these portions is deposited in the various small branches, r bays, or, in fact, in any positions where a sudden change akes place in the rate of flow; and, when this law is skilfully pplied by the engineer, it may be made to co-operate very fficaciously in the improvement of the course of the stream. But in the lower portions of the river, where the descending elocity of the water is destroyed by the meeting with the ea, the sand and mud are deposited gradually all over the

surface of the bed, giving rise to the deltas which are so characteristic of the mouths of rivers, particularly in tideless seas, such as the Mediterranean and the Gulf of Mexico.

According to the natural laws of gravity the velocity of the waters in a river would continually increase, agreeably to the rates of inclination of its bed, did not the friction upon the sides and the bed increase at the same time with the velocity, and in a much greater proportion. The friction also modifies the rate of flow of the several separate portions of the transverse section, causing it to be greater in proportion to the depth or volume over any particular part of the contour. There is, in almost all rivers, a zone where the depth is greater than in the other parts, and where, consequently, the velocity is greatest; this zone is called the "thalweg" by foreign engineers, and forms usually the navigable channel. Beyond it there are frequently other zones of still water, and in some cases these are characterised by currents flowing in an opposite direction to that of the main stream. In the thalweg itself, also, the velocity is not the same at the bottom than it is at the surface, where in rivers of ordinary depths it is at the maximum. It is usual to consider the mean velocity to be about four-fifths of that of the maximum.

The following table is extracted from the "Cours de Construction," by Sganzin; it shows the volocity of some of the most important rivers, principally in western Europe.

				ft.	in.
Mean velocity of the Seine, below Paris . . .			per second	2	3
,,	Thames at London, flood tide		,,	3	0
Velocity of the Tiber at Rome, low water			,,	3	4
,,	Danube at Ebersdoff	,,	,,	3	6
,,	Loire	,,	,,	4	4
,,	Rhone at Arles	,,	,,	4	10½
,,	,, Beaucaire	,,	,,	8	6
,,	Durance below Sisteron	,,	,,	8	6
,,	Maragnon, S. America	,,	,,	13	0
,,	Rhine varies from 3 feet 2 inches to about .			14	0
,, of a torrent produced by the melting of snow by the sudden action of a volcano				25	7

From the circumstances connected with the origin and bsequent flow of rivers, it follows that their volumes are posed to considerable variations. Thus, the melting of a ll of snow, or a sudden storm, may cause the waters to rise a very anomalous manner, producing in those parts of the urse which are beyond the influence of tidal action serious odifications in the velocity and depth of the water, as well in the cross section. It becomes important, therefore, fore commencing any works for the improvement of a river, ascertain the precise range of its variations of volume, and e numerous causes which may affect, not only the district rained by the principal stream, but also those of its affluents. ndeed, when rivers are of great length it frequently happens at the floods of the various subsidiary hydrographical basins ccur at very distant epochs, and introduce numerous causes f irregularity in the flow. As, for instance, in the case of he Mississippi, the freshets from the upper valleys of the lississippi and Missouri come down at different periods from hose of the Ohio and Tennessee valleys, and, generally peaking, at a later period of the year. It is observed hat the floods of the Ohio, under these circumstances, cause he waters of the Mississippi to be, as it were, penned back for a considerable distance; and equally the floods of the Mississippi occasionally pen back the waters of the Ohio for many leagues. The same remark will apply to most great rivers; but, in our own country the extent of the hydrographical basins is not sufficiently great to allow of much irregularity of this description; and we may consider with tolerable safety that our rivers, above the influence of the tides, are at the lowest in the months of June, July, August, and September, and that the floods occur in the months of December, January, February, and March.

Under ordinary circumstances we find that the banks of a river resist less than the bottom, and that the width proportionally is greater than the depth. The tendency of the constituent particles of the banks to fall down by the effect of

gravity adds to this excess of the one dimension over the other, and as the larger and more solid materials thus carried low from the sides remain at the bottom, they also serve to augment its stability by their greater resistance. In long level plains the velocity of the stream necessarily diminishes, and any accidental obstacle acquires increased power to deflect it from its natural course, which would be upon the line of greatest longitudinal fall. Should the bank be of a harder and more resisting nature on one side than the other, or should any natural or artificial projection exist, the stream will turn towards the other side; and its bed may thus become sinuous, and present such an increase of length as materially to retard the flow of its waters. In winter, it is also to be observed that, if the upper surface be frozen over, the whole of the abrasive action of the stream is exercised upon the bottom which it will deepen so long as the water thus flows, as it were, in a pipe.

The researches of Gnglielmini, Manfredi, Frisi, and Dubuat, may be consulted with signal advantage by engineers about to undertake works for the improvement of rivers; and of late years the notices of Messrs. Stevenson and Scott Russell, with the records of what has been executed in the United States and France, will be found to throw considerable light on the subject. It may be, however, sufficient at present to call attention particularly to the following laws deduced by D'Aubuisson, viz.—that the resistance of elbows or deviations is generally small; and that the current acting upon the concave bank destroys it the most rapidly, and gives rise to an increased depth in front of it, whilst the deposits and silting take place near the convex shore. It may also be observed that in mountainous countries rivers run close to, and are deeper near, the feet of the steepest hills, especially when these are exposed to the prevalent winds of the locality. And, lastly, it will be found, in rivers flowing over a sandy or gravelly bed, that there exist a series of zones in which the water retains a very slight velocity with considerable com-

rative depth; and that at other parts the bed rises in such manner as to form bars, over which the water flows in a allow rapid stream. These bars are generally situated ar bends of the stream, and they serve to retain the waters wing from the upper part of its course.

It follows from what has been said above, in this and the eceding chapter, that the works required for the improve-ent of the channel of a river may be directed either to gularize its flow in such a manner as to retain a sufficient pth of water for the purposes of navigation or of adaptation manufacturing or irrigation uses; or simply to defend the rrounding country from the ravages of inundations, whether ey be caused by floods from the upper districts or by e tides.

The first inquiries to be made in either case must be rected to ascertain all the variable conditions of the flow ad volume of the river, the nature of its bed, and both its lan and section. As far as regards the adaptation of any ream to manufacturing and irrigation uses, the principal oint to be decided will always be the height to which the ater may be penned back, because evidently upon this, to a reat extent, will depend the power it can produce and the urface it can irrigate. But with respect to its adaptation to he purposes of navigation, the questions of detail become more complicated. It frequently happens that the transports nly require to be effected in one direction, and that they an only be effected under certain conditions of velocity and lepth. The width to be given to the new navigable channel may also depend upon circumstances extrinsic from those of the river itself, so that a careful examination of the commercial relations of the district is as necessary as that of its physical nature.

When the upper part of any hydrographical basin is situated in a densely-wooded country, the stream is frequently capable of being rendered fit to transport floats or rafts, by giving it the breadth and depth required by means of a series

of artificial basins so disposed as to allow the water to escape at stated intervals, in flashes, upon the top of which the rafts are carried forward to the next basin. This system is only applicable to mountain streams with a small depth of water, and to such countries as produce much timber; it can, therefore, be seldom required in our own country, although in the colonies it might often be of great service. The most efficient mode of forming the sluices seems to be to construct retaining walls at an angle from the banks towards the centre of the down stream, so as to reduce the open way in the axis of the river to that which is barely necessary to allow the rafts to pass. This open way should be continued for a short distance parallel, until arriving at the sluice, beyond which it widens out again. The width between *a b* and *c d* may vary from 24 to 13 feet as a minimum; the length should be about 2½ times the width. A sluice, working upon horizontal hinges at the bottom, and maintained in its position by a locking bar at the top, so that directly the bar is removed the sluice may fall, is used in some cases; whilst in others, the water is penned back by means of a series of movable blades resting against a set-off in the stone sill at the bottom, and a locking bar at the top, which is not withdrawn until all the blades are removed. With the latter arrangement the velocity of escape of the water is somewhat diminished, and the danger from the cataract thus produced, both to the raft and to the building of the dam, is diminished. The minimum clear depth of water over the sill, at the moment of flashing, should be about 1 foot 8 inches.

The best position for the opening of the sluice, so far as the conditions of the flow of water only are concerned, is in the centre of the stream; but if there be a towing path, it is

lvisable to bring it as near to the latter as possible. It ay also happen that in some positions it will be necessary join a lock to the flashing sluice, in which case the best sition for the lock is unquestionably in the still water on e opposite side to the sluice. The side walls of the lock amber, and the floor of the tail bay, with its retaining walls, ust be protected against the effects of the cataract from e sluice.

When it is possible to obtain, either artificially or naturally, depth of about 3 feet, a river becomes navigable for barges. the rate of fall in the longitudinal direction exceed from to 8 in 10,000, the barges can only descend loaded. It is ual, however, to regard an inclination of 1 in 2000 as e maximum which admits of transport in the two di-ctions of ascent and descent. The river Rhone has an clination of from 7 to 8 in 10,000, as quoted above, and by e aid of a class of steamers constructed especially for that ver, with some peculiar arrangements of their machinery, e ascending navigation is carried on with tolerable success. ut on the river Lys, in Belgium, where the haulage is rformed by horses, the rate of flow, produced by an inclin-ion of 1 in 2000, might render the ascent difficult were it t retarded by the aquatic plants, which it is strictly for-dden to cut.

Barges naturally vary much in their dimensions, according the nature of the river upon which they are employed. he extreme limits of variation appear to be, in length, om 50 to 230 feet; in width, from 6 feet 6 inches to 23 feet; d in draught of water, from 2 feet 6 inches to 6 feet inches. Evidently, then, it is important to ascertain the mensions of those frequenting the waters of the main ream, or of any of its affluents, before commencing any orks for the improvement of either the former or the latter.

In many instances it will be found sufficient for all ordinary rposes of navigation to regularize the outline of the bank arest to the thalweg, so as to secure a uniform depth of

water, and a freedom from abrupt changes of direction, in the part of the channel close to this bank. The towing-path would then, naturally, be formed on the same side; but it is perhaps as necessary to lay down as a general rule, that a towing-path ought to be formed upon the bank under the prevailing wind. The conditions really affecting the determination of its position are that the haulage take place in as direct a line as possible, and that there be very few impediments to the passage of the ropes. It may occasionally happen that a second towing-path is required, but generally speaking, in these cases the width need not exceed one-half of that of the principal path. Both of them should be kept at such heights as to allow of their being above the water line, so long as the navigation can be safely carried on; directly, however, the waters of a river rise to such a height as to cause the river to flow with a dangerous velocity, it is advisable that they become submersed, in order effectually to prevent the bargemen from attempting to proceed.

The width of a towing-path is usually from 12 to 13 feet; mooring-posts are required on the opposite bank. In passing under bridges the towing-path should be carried under the land-arches, if possible, so as to obviate the necessity for detaching the tow-ropes. When it is not possible to carry the path in this position, it will be necessary to insert rings into the masonry of the bridge, or to place mooring-posts in the banks, or to adopt some other method of attaching the boats during the period that the tow-rope is being carried forward.

But, in the majority of instances, it is necessary to do far more than merely construct towing-paths. The depth of rivers in the summer months is usually insufficient to allow the continuance of navigation; in other seasons the velocity may be too great; sometimes the thalweg may shift from one side to the other, or the banks may be exposed to be frequently washed away. The first object to be obtained is, then, to maintain the river in its bed, and to create for it a

channel of such dimensions as to ensure, at the lowest waters, sufficient width and depth; and the second, to regulate its velocity so as to ensure favourable navigation in either direction. They may be obtained, either by forming a series of reaches of still water in the bed of the river itself, communicating with one another by locks; or by means of a lateral canal; or occasionally by constructing a secondary bank, submersible whenever the waters rise above certain definite levels.

If the river flow under such circumstances as to form a succession of islands dividing its waters into two or more branches, advantage may be taken of this circumstance to divert into the main or navigable channel the waters usually flowing in the subsidiary branches, by means of submersible dams or by movable barrages. It is also possible to convert the main channel into a canal, by forming a lock at the extremity of such a series of islands, and placing waste weirs upon the small communicating channels between them. Such a lock will also, of course, increase the depth of water reserved for navigation, and destroy any injurious velocity of the main stream; but even when it is found inexpedient to construct any works of this class, the fact of confining a stream within a regular channel, and thus concentrating its scouring action, will render great service by eventually lowering the bed of the river.

If the river suddenly diminish in depth on account of the widening of its bed, it may be improved by contracting the latter; the manner to be varied according to local circumstances. Thus, in the case of the Midouze, a river falling into the Adour, in the south of France, the widening out of the channel in several of its bends was corrected very successfully by planting aquatic trees, such as willows, osiers, &c., upon the banks, so as to leave a clear, regularly outlined, water-way, at the same time that all reefs or other projections in the channel were removed. When the velocity of the stream is small, this system appears to answer very well;

because the artificial banks thus formed soon become silted by the deposition of any mud or sand in suspension in the waters of floods, which is facilitated by the retardation of their flow in consequence of the obstacles formed by the trees, and as the roots of the willow tribe strike quickly they soon solidify the deposits. As the water-way becomes also thus contracted, there is at the same time created a tendency to lower the bed of the river and to cause the water to flow permanently in the open channel thus left. There is a great simplicity in the means adopted in this case; the materials employed are inexpensive and easily procured, and they possess this advantage, that they do not in any way interfere with the normal régime (or conditions of flow as to volume and velocity), in the open channel, at least.

In rivers exposed to sudden and violent floods, however, the trees, and the deposit around them, would be inevitably carried away; and it becomes necessary to construct the longitudinal banks required to concentrate the summer or low waters in a more substantial manner. But, in such cases, it is equally necessary to defend the usual or natural bank of the river by some system which shall enable it to resist the abrading action of the current. On many rivers, instead of constructing longitudinal banks, a series of transverse spurs are carried out into the stream, for the purpose of giving rise to corresponding pools of still water in which the silt or gravel carried down may be deposited. These spurs, in fact, are intended to exercise the same influence upon the stream of rivers that groins do upon the currents of the sea-shore. In both cases, however, their useful effect is very questionable; that is to say, when compared with their cost. Unless they are in close proximity to one another, the counter-current produced by these spurs is found to corrode the banks in a serious manner on the down side of the projection. If they are very close together, their developed length will be found to be nearly equal to that of the more logical system of longitudinal banks; and in the latter case, moreover, there

s less danger to be apprehended from the changes of direc-
ion produced by the irregular interferences with the line of
he current. Experience appears to warrant the assertion of
he general rule, that the most effectual method of deepening
he bed of a river, and of regulating its flow, is to confine it
etween longitudinal banks, which may occasionally require
ateral openings or waste weirs, so as to allow any sudden
reshets to escape directly they attain a dangerous height.

The submersible banks, or dykes, as they are sometimes
alled (and the name will be retained for the purpose of
esignating more clearly the difference between the dykes and
he banks), may be executed either in rough blocks of stone,
r concrete, of masonry, of woodwork, of fascines, or of
anniers filled with gravel or with rubble-stone. The feet of
e banks may also be protected in the same manner; and if
y portion extend much below the permanent water-line, a
mbination of several of the above systems may be employed,
in the case of the banks of the Rhine. In almost every
se, however, the determining motive in the choice of
aterials is to be found in their relative cost. As the two
asses of works, viz., those for the defence of the banks and
e construction of the dykes, are so nearly identical, the
escription of the former, by far the most important, will be
ven in the greatest detail.

The rubble facing of river banks may be resorted to when
one is plentiful and at a very low cost, for it is to be
bserved that the quantities required are very considerable.
he peculiar advantage of this system is that the rubble
asily slides down into any place where the water has attacked
nd undermined the banks; and it may be executed under
lmost every condition of the level of the water in the river.
he largest stones which it is possible to obtain ought to be
mployed, because they are displaced with the greatest
ifficulty. The slopes, when finished, should be dressed
olerably smoothly to a minimum inclination of 1½ to 1; the

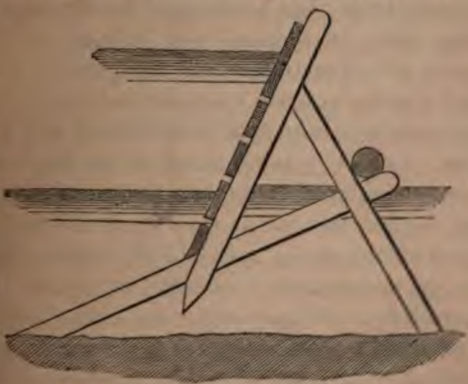
thickness must depend upon the nature of the bank supported, and the degree of erosion it is required t[o com]pensate.

When stone is dear, the slopes may be pitched i[n the] portion above the usual summer level; this pitching, [how]ever, does not support the banks, but only serves to [defend] them against any erosive action of the currents or desc[ending] ice. In the execution of this pitching the most imp[ortant] part is to be found in the foundations, which must be a[ble to] resist the undermining effects of the current. If th[e bed] and sides of the river be of a solid nature, loose rubble m[ay be] employed; but if they be of a nature to yield easily, it may be necessary to defend the feet by a single, or even by a double, row of piles; the woodwork being kept as low as possible in all cases. The inclination may vary from 1 to 1, to 2 to 1; the longer slopes requiring a less thickness of pitching, and resisting the action of the currents more effectually; at the same time they will be found to carry waves to a higher point, if the river be sufficiently wide to allow of their formation. The thickness will be regulated by the rate of inclination and the force of the currents; but it is usually from 9 to 14 inches at the summit, and increases at about the rate of 1 inch to

foot of additional depth. In order to resist the action e currents at the water lines, the courses should be ed, or, at any rate, they should not preserve their ntality for any great distance.

pes may be protected from the effects of a sudden flood, rapidity of execution is desired, by means of a timber ;. Guide piles are driven, either vertically or in an ied position; they are connected at the top by whales, n the inside they are lined by planks laid horizontally, acked by earth. This od of defending banks ers is very costly, and nly be employed defi- ly in positions where r is plentiful, land ole, and the length to otected not very con- ble. It has been ed on the banks of

celdt, and in some of the Atlantic cities of the United s. On the banks of the upper Po, in the Piedmontese



inions, a very economical system of temporary wooden

defences was introduced by an Italian engineer, of the name of Magistrini, which has answered very well in every instance where it has been employed, for the purpose of turning aside any current acting upon projecting spurs or abrupt elbows on the river banks.

The Piedmontese engineers have also endeavoured to introduce a system of defence walls consisting of triangular prisms of concrete, dressed eventually to a slope of 45° with the horizontal line. In other cases, as upon the banks of the Medway, river walls have been executed by forming a general bed of concrete, which is further protected by rubble-stone pavement, tied down by a series of stakes driven into the bank itself.

Fascines are formed by tying together a great number of small twigs of brushwood, laid longitudinally, by other twigs placed at intervals varying with the diameter. The wood ought to be from five to six years' growth, the small and large ends being respectively kept in the same direction, and at least two-thirds of the total quantity used in a fascine should pass from one end to the other, nor should any twig exceed 4 inches in diameter. Small fascines are from 5 feet to 6 feet 6 inches long, and about from 1 foot 6 inches to 3 feet 6 inches in girth at the large end. In Flanders and Holland the length is usually made from 8 to 13 feet, and the girth in the center from 1 foot 4 inches to 1 foot 8 inches; and upon the Upper Rhine the length is made from 13 to 16 feet, with a girth of from 3 feet 6 inches to 5 feet 6 inches at the larger end, and from 1 foot 8 inches to 1 foot 10 inches at the smaller. Sometimes the fascines are tied together at the ends, so that the small extremity of one may join the large extremity of the other, and the name of "sausage," or "gabion," is given to the assemblage. Military engineers make their gabions about 20 feet long, and 3 feet in girth on the mean, with bands at distances of from 1 foot to 1 foot 6 inches; in Holland the gabions are made from 24 to 27 feet long, from 1 foot

inches to 1 foot 8 inches in girth, and with bands at every inches apart; and upon the Upper Rhine the gabions are ade from 2 feet 6 inches to 3 feet 4 inches in girth.

In Flanders and Holland, when a bank is to be protected y fascines, if the corrosion take place above the ordinary ater line, and the natural slope of the ground below be such s to support the weight of the bank, the fascines are laid in orizontal courses, with the small end towards the land and e butt end to the water. The ends of every succeeding yer are set back from the line of the layer below it, so s to form a regular batter, and the whole body is tied gether by means of stakes 4 feet long driven through each scine as it is placed. The heads of these stakes project om 6 to 8 inches, and they are tied together by hoops passg alternately in and outside of the heads. Gravel, clay, sand, r shingle, are then firmly rammed upon the fascines, so that eir surface becomes perfectly level before proceeding to lace another layer. The batter of a slope thus built up in scines may vary from $\frac{1}{3}$ and $\frac{1}{2}$ to 1 base to 1 in height.

When the bank is corroded below the ordinary water line, he course usually adopted is, to form a species of raft of abions strongly tied together and fixed into the banks by takes, with their ends projecting into the stream. Other abions are placed upon these in a direction parallel to the ank; and fascines alternately crossing one another in the ody of the raft, but presenting always at the river end their mallest extremity, are laid upon this description of grating. The several layers of fascines are joined together by stakes, ound which bands are placed as before, and the whole tructure is sunk by being loaded with gravel or stones, forming, in fact, a species of elastic matlass adapting itself to the orm of the river-bed. The force and velocity of the current odify to a certain extent the resistance of the gabions; and is for this reason that in the districts of the Upper Rhine e dimensions given to the gabions are greater than those dopted where the river runs more sluggishly.

Upon the banks of the Rhine panniers filled with gravel are occasionally employed. They are formed of osiers or willow-twigs woven together in the form of baskets, about 6 feet 6 inches long by 3 feet 4 inches high and 2 feet wide, when rectangular; the length is made about 7 feet when the panniers are triangular, the sides measuring 4 feet 4 inches; when they are circular, the length is made 10 feet, and the girth about 7 feet. These panniers are thrown down, sometimes at random; at others they are sunk over the positions they are intended definitively to occupy, and fastened by means of stakes. In several instances, large hollows in the banks of rivers in these districts are filled in with panniers of the above description, and the upper surface is further protected by means of a pitched stone slope laid in the usual manner.

The use of fascines can, however, only be recommended in countries where more durable materials are extremely expensive, or where great rapidity of execution is required. They are exposed to very rapid decay, and to the attacks of numerous animals. In England, they are hardly ever employed by other than the Royal Engineers; and it is in Holland only that they are habitually employed in the formation of longitudinal submersible dykes for the regulation of the channels of rivers. Whatever description of material be adopted, the most important point to be observed is, that the work for the defence of a bank should be executed with the greatest rapidity, and before the corrosions can attain any dangerous extent, which might allow the formation of any secondary branches, or any permanent alteration in the régime of the river.

In all works intended to improve the navigability of a river, extreme care is required in attempting to alter its natural conditions, whether of width or of depth, because the results of any interference with them are always very uncertain. It is preferable at all times to maintain the river within the limits nature appears to have traced for it under its normal flow, rather than to endeavour to introduce great modifications, even though they may appear highly desirable.

Thus, in several instances, when it has been attempted to shorten the course of rivers by diverting them into new and straighter beds, the water has eventually formed for itself a course of precisely the same character as the original one. This is particularly true with rivers that run upon a sandy bed, when they follow a sinuous line, and it is attempted to shorten the distance between any of the principal beds; for the slightest inequality in the resistance of either the bed or of the banks will give rise to currents such as are able to overthrow the new works. It may be laid down as a law, that the straightening of the bed of a river is only to be effected to a limited extent, one which will depend upon the nature of the materials over which it flows, and the volume of water it carries.

It may be possible to improve the navigability of a river either by dredging, or by the closing up of the secondary branches, without resorting to the construction of submersible dykes; and at almost all times those operations are productive of advantage, if executed with proper precautions. Thus, dredging may be resorted to, for the removal of any shoals in that portion of the course of a river where the navigation is designed to take place. But in some cases, as, for instance, when the water is kept back in a series of pools by means of such shoals, their removal may be attended by the lowering of the water line in all the upper parts of the river. The nature and mode of formation of such shoals must therefore be carefully ascertained before an attempt is made to remove them.

In closing the small branches which run between the subsidiary islands so frequently to be met with in rivers, the course usually adopted is, to carry out the dam from either side towards the center. In proportion as the dam advances the waterway becomes contracted, and naturally the velocity is increased to such an extent as to render the closing of the central portion a very difficult operation, because the bed is deepened, and the materials thrown in are often carried away

immediately. Sometimes the aperture is closed by driving piles in front of it, between which hurdles are placed so as to diminish the current; sometimes sheet piling is driven; and occasionally old boats or pontoons laden with earth or stones are sunk. Under all circumstances, it is necessary that the materials required to carry the dam up to its full height should be prepared beforehand, so that no opening should be left through which the water should flow. Loose rubble-stone dams are used in some places, and they become eventually watertight by the deposition of the mud and silt brought down by floods. Fascines are used in other cases, either by being thrown down at random, or by being sunk in large rafts in the manner adopted in Holland and Flanders.

The best position of the dam closing such small branches is a subject of some obscurity. When it is placed at a considerable distance below the point of bifurcation, the water becomes stagnant before arriving at the dam and deposits the silt required to render it watertight. When it is placed close to the point of bifurcation, the currents and floating ice are likely to damage its construction; and moreover the length in such positions is considerably increased. The only general rule appears to be, that the dam should be placed sufficiently near, but below the extremity of the island, to allow the alluvial deposit to reach it easily.

A very important observation is to be made with respect to the diversion of the waters of secondary branches into the main stream; namely, that the depth of the latter will be but slightly increased if the river flow freely, because the volume of water discharged increases more rapidly than the height. Observations upon the meeting of rivers pointed attention originally to this law, and theoretical reasoning confirms it. Some interesting facts connected with this subject will be cited hereafter; but it may be now observed that the effect of any dam or dyke which offers an obstacle to a current is to produce a contraction of the waterway, causing the plane of the water to rise on the up side and to lower on the

down side. The inclination of the surface in the portion so contracted is naturally increased, and it is possible that it may be so to such an extent as to interfere seriously with the navigation. If the bed of the river itself be of a light and easily-moved nature, it is equally possible that the increased velocity of the current may deepen it; but, under ordinary circumstances, the materials thus removed are only displaced, or they are deposited in the lower part of the course, where the river in fact begins again to widen out to its natural dimensions. The practical rules usually admitted by engineers in works connected with the narrowing of rivers for the purpose of increasing the depth may be briefly stated to be as follows:—

1. The longitudinal dykes should never be carried to a height above the mean level of the water in the river; the usual height above low summer water level is 2 feet; during floods, they should be entirely under water. 2. The velocities of the different channels vary in the inverse ratio of the cube roots of their widths. 3. The cubes of the heights are in the inverse ratio of the widths of the beds. 4. As much as possible it is advisable to preserve the natural waterway, and to make the capacity of the narrowed pass equal to that of the ancient bed in such portions as are free from irregularities. If it be necessary to displace the river, it should be directed, in preference, to the bank or portion of the channel most likely to yield to the scouring action of the waters.

The attention of engineers was called to the peculiar phenomena connected with the junction of rivers by a very remarkable letter or report by Gennété, an Italian engineer, addressed to M. de Raet, burgomaster of the city of Leyden, about the year 1755. In this letter he showed that a large watercourse could receive all the water brought into it by an affluent of considerable volume, without any sensible augmentation of the height of the water line, or without any increase in the width of the bed. The reason he assigned for this was, that at the same time that the volume was increased the

the case of the Seine above Paris, the waters upon the right bank are charged with the calcareous salts brought down from the upper valley of the principal river, whilst those upon the left bank are charged with the magnesian salts and the earthy matters brought down from the valley of the Marne. This fact is, perhaps, more distinctly marked upon the shores of the great lakes and of the ocean; for the muddy waters of the Rhine may be distinguished from the deep-blue waters of the Lake of Geneva, and the stream of the Amazon may be traced in the Atlantic, at distances, in both cases, far removed from the points of their embouchures.

A cursory examination of a map will show that the law which appears to regulate the formation of the deltas or alluvial deposits at the mouth of all great rivers is, that these divide into a series of subsidiary branches before falling into the sea, and that they almost always project beyond the line of the sea-shore, forming, as it were, projecting promontories of a rounded outline connected with the original line of coast: the Volga, Danube, Rhine, Rhone, Po, Nile, and the Mississippi, Ganges, Irrawaddy, &c., may be mentioned as illustrations. The lands around these deltas are flat and marshy, andconsist of sand and mud; the channels winding through them are shallow, and exposed to change in their direction and volume without any apparent cause. The rate of deposition depends upon circumstances equally beyond ordinary calculation, and varies in every particular river.

The formation of these deltas arises from the deposition of the matters brought down from the upper portions of the river courses, caused by the difference in the specific gravities of the fresh and salt waters, and the annihilation of the onward movement of the former by the tides or the littoral currents of the latter. The tendency to the deposition of alluvions is also increased by the diminished inclination and velocity of the rivers near their mouths, and in some cases this diminution is sufficient to cause the rivers to overflow the lands above the delta itself, so as to render it difficult to

certain its precise limits. The formation of the subsidiary anches noticed in the deltas is to be attributed to the reflux the waters in the main channel, and they are the most umerous in the deltas which advance with the greatest pidity and occupy the greatest areas. But if the littoral urrent run with great velocity and transport any alluvions, it ill give rise to bars at the mouth of the branches; if it be ee from alluvions, it will disperse the materials it may etach from the extremities of the deposit, or, deflecting the ne of outflow of the river, it will give rise to a delta llowing the direction of the resultant of the two forces. ccasionally also the tidal waves will give rise to a bar across e mouths of the branches at the points where they begin to utralize the outward flow of the soft water.

The majority of the English rivers fall into the sea at the ttom of large open bays, and in those cases the deposition the fresh and salt water alluvions takes place in the form banks or shoals in those portions of the bay where the spective currents of the sea and of the river meet. These oals vary constantly in their outline and position in such vers as the Thames and the Severn, and in the Seine, oire, and Garonne in France; and form very serious impediments to the navigation. In many other cases, as in the vers upon the Suffolk and Norfolk coast, and upon the uthern shores of England, the deposits take place across e mouths of the rivers, according to the law noticed in the st paragraph. But it is to be observed that, although these rs diminish the depth of water immediately over them, the ver above may often retain a very considerable depth; deed the effect of the bar is often precisely analogous to at of a dam. Thus, the Rhone has rarely a depth of more an 6 feet 6 inches in the passes of its delta, whilst at Arles e depth is not less than 43 feet. At the mouth of the Po Volano the pass has only a depth of 2 feet 6 inches, whilst out seven miles further up the depth is not less than 10 feet;

and the same fact has been observed at ... upon the channels Nile and of the Mississippi, but to a far greate ... ation. These

At the junction of streams in the interior, the ... same phenomena may be observed to take place as those which ... been already noticed as occurring on the sea-shore, although of course upon a very diminutive scale. Should one of the confluents bring down much alluvial matter, and flow with considerable velocity into a stream of a different character, the deposit may take place either in the fan-like shape of a delta or as a bar; and in the former case it is possible that the stream may divide into a number of branches, whilst in the latter the relative depths of water over the bar and above it may present all the essential conditions of those connected with rivers discharging into the sea. But the absence of the tidal action gievs a greater fixedness and simplicity of character to the manner in which these deposits are effected, and consequently allow of their being treated with greater comparative facility, whenever it is desired to improve the navigation of a river previously obstructed by them. But it must always be borne in mind, whether it be a question of combating the natural operations of the laws affecting the flow of large or of small streams, whether strictly inland or in estuaries, that unless some other natural law of the same class be made to counteract the particular one producing the state it is desired to remedy, all engineering contrivances or mechanical operations will either be vain, or at most produce but a temporary effect. Nature must, in fact, be made to correct itself.

If, therefore, it be desired to obviate the inconvenience arising from the deposition of the alluvial matter across the embouchure of an affluent into a greater stream, and this deposition be found to be caused by the annihilation of the velocity of the affluent, in consequence of the greater velocity of the main stream, the only effectual mode of proceeding would be, to increase the velocity of the affluent by diminish-

s outflow during perhaps, if it follow a devious course, by then a rise fall by means of a new and shorter channel. es may also, in some cases, be possible to effect the desired ffect by forming an artificial embouchure at some other oint on the river, where the régime of the main stream might very different. But whatever precise details be adopted, ey must resolve themselves finally into the means of se- iring an equality of velocity in the confluent rivers, and so recting the respective axes of their flow as to prevent the ream of the one from setting across the line of the other.

Should the deposit assume the form of an ordinary delta, nd give rise to a subdivision of either or both the rivers ito a series of small branches, the best course to adopt is, to orm new beds for the waters brought down, of such sectional rea and inclination as to ensure the meeting of the respec- ive streams under those conditions which would allow the lluvial matters to deposit themselves upon lines of direction orresponding with the resultant of the two new channels. As the tongue of land thus formed would continue to advance, t would be necessary to provide for the inevitable changes it would superinduce upon the point of junction.

On the sea-coast, if it be desired to lower the water line in the branches of a delta, Gennété's experiments, and all sub- sequent experience, show that the most efficient method of proceeding is, to increase the velocity of flow by causing a greater volume of water to pass through a given channel in the same period of time, rather than by increasing the surface of the waterway. This is especially the case when the bottom f the river is composed of a material capable of being easily emoved, because the bed itself will be lowered in consequence f the increased transporting power of the water. Evidently hen, in such positions, the width of the subsidiary channels s the only element which is susceptible of modification by rtificial means, at least economically, and it should in all ases be reduced as much as possible. All the small branches hich can conveniently be suppressed should be closed, so as

to concentrate all the action of the water upon the channels it is proposed to retain for the purposes of navigation. These remarks are principally made with reference to tideless seas; the difference in the system to be adopted where the range of the tides is considerable is substantially unimportant, and will be mentioned hereafter.

In the case of a bar formed across the mouth of a river on the sea-shore, human means are almost powerless if the littoral current bringing the alluvions be strong, and not susceptible of being diverted. To a certain extent it is possible to augment the depth of water above the bar by concentrating the outflow of the river, and guiding it by means of parallel banks in such a manner as to direct the scouring action of the land water so that it should remove the alluvions either into the deep sea or again into the littoral current which should carry them further on. But the success of such measures will only be temporary, and the history of the ports of Rye, Dunkirk, Aigues-Morte, and others, show that it is hopeless to endeavour to struggle against the ceaseless unwearying operations of nature. New channels may be carried out through a bar, and for a time kept clear by the scour of the upland waters and by dredging; but sooner or later the angle between the original outline of the bar and the projection of the new channel becomes filled in, and if the littoral current should not then be able to sweep off the alluvions carried to the front of the pass, the bar will begin to reform. The pass or channel must then be carried further out to sea, or kept open artificially at a constant and excessive cost. It is possible to direct the tidal action in some positions, so as to produce considerable modifications in the ordinary laws affecting bars, in the following manner—which is applicable to either of the cases connected with the entrances to rivers hitherto considered.

In the lower zones of rivers exposed to tidal action, the depth of the navigable channel may be increased by causing a larger volume of water to enter with the flood, and confining

outflow during the ebb within the limits of the channel. then a river divide into several branches, the subsidiary es may be closed by means of dams, with sluices opening ly with the flood, and so arranged that the water thus in- oduced into the secondary channels shall be forced to escape the one it is proposed to deepen. This object may also casionally be effected by causing the secondary channels to rive their supplies from the principal one at some point on e up stream; but it will generally be found that in such ses the velocity of the ebb tide will be inconveniently eat for the ordinary purposes of navigation. In fact the condary channels would become sluices, whose waters would t to scour the pass. The advantage proposed to be gained these instances is to be found in the fact that a large quan- ty of water is forced to flow through a narrow channel, and e velocity is consequently increased, thereby enabling the ver to remove the lighter materials of which its bed is com- sed. But the whole success of works intended to produce ese results must depend upon the relative proportion of dal water which can be made to enter, or upon the increase velocity in the outflowing stream. It follows, therefore, at any diminution of the water surface at high tide is likely affect seriously the power of a river to maintain a clear vigable channel, unless the latter be contracted at the same ne in a corresponding degree.

The results obtained at Nieuwe Diep, upon the Clyde, the ee, the Thames, and the Seine, confirm what has been ove stated; and, moreover, the practical deductions to be de from them appear also to warrant the assertion that it preferable to obtain the increased scouring action of the e by forcing the water to flow to a higher point in the river, her than to allow it to spread near the embouchure. The rks of Nieuwe Diep have already been described; those on the Clyde and the Dee and the Ribble have consisted the erection of longitudinal dykes parallel to the axis of river, retaining the stream within a narrow channel during

the latter portion of the ebb, and in the removal of obstructions to the propagation of the tide wave to a greater distance from the embouchure than it had previously attained. In the Thames, the removal of the Old London Bridge, which acted as a dam to the tide, has been attended by an increase in the duration of the flood, and an increase of depth at high water varying from 1 foot 8 inches at Teddington to nearly 7 feet at Blackfriars Bridge. In the Seine, the concentration of the tidal action, by means of the lateral banks lately formed between Caudebec, Villequier, and Quillebœuf, has deepened the river a little more than 9 feet, partially destroyed the bore, and increased the duration of the flood tide one hour. Nor does there appear to be any reason why these results, so advantageous to the interests of commerce, should not be further developed, if the existing obstacles to the propagation of the tide wave into the interior were removed upon the two last-named rivers.

Precisely opposite results have attended the diminution of the scouring reservoirs naturally existing beyond the channel of the port of Ostend. The marshes or low lands, there flooded at every high tide, have been gradually reclaimed, and as the channel was not carried further up into the country, so as to create an artificial backwater whose conditions of discharge should replace those under which the waters over the low lands escaped, the silt brought into the mouth of the harbour by the littoral current has considerably diminished the depth in the entrance. Dredging and sluicing have been resorted to in vain, although conducted with all the practical skill and persevering energy of the Dutch and Belgian engineers. For, however powerful the effects of sluices may be, they are far inferior to those of the alternate currents of the flood and ebb tides spreading over large spaces. Great circumspection must therefore be exercised, and long, elaborate, and skilful investigation made, before any port or river is deprived of the scouring action of the tides. The alluvial deposits may perhaps tend naturally to diminish or to destroy

his action; but it must be retained as long as possible, and ur efforts directed at all times rather to increase than to iminish its power.

Finally, it cannot be too often repeated that, before underaking any works which may interfere with natural causes so omplicated and so numerous as those which affect all river r sea engineering, the most cautious, patient, and at the same ime comprehensive view of the whole subject must be taken. n the whole range of professional practice the questions conected with hydraulic engineering are the most abstruse, and equire the assistance of all the collateral sciences, and the rofoundest acquaintance with the great laws of nature affecting the configuration of the globe. Empirical knowledge is ut of little service, and the local engineer, if devoid entirely f theory, is as likely to fall into serious error as to hit upon he truth, by trusting alone to his limited experience. And it is upon this score that we may account for the fearful waste of money, and the ruin of many ports, which have been entrusted to the care of those whom it is too much the fashion to admire in our own country under the specious title of "practical men." Extremes are dangerous in all things; and it must be understood that, whilst thus advocating the necessity for wider and more theoretically-scientific examination of the circumstances affecting the sites of any proposed hydraulic works, due appreciation is accorded to the value of local experience. Theory, practice, and science must mutually be brought to bear in all such cases, and the more of all of them the better. No one alone will suffice.

The only axioms which can be safely laid down are:—

1. That no change should be introduced in the natural régime of either rivers or the sea, unless absolutely necessary.

2. That all our efforts should be directed to bending the powers of nature so as to ensure their co-operation in bringing about the state of things we desire to secure. The motto of the hydraulic engineer should be that placed by Leupold at the head of his "Theatrum Machinarum Hydraulicum:"

"Artis est naturam imitare."

APPENDIX.

TABLE I.—COEFFICIENT OF DISCHARGE THROUGH RECTANGULAR ORIF[ICES] GIVEN BY PONCELET AND LESBROS. See Part III., page 52.

Head over Center.	Height of Orifice.					
	8 in.	4 in.	2 in.	$1\frac{5}{48}$ in.	$\frac{19}{24}$ in.	[illegible] in.
$\frac{19}{48}$ in.	...	...	...	...	...	0·71
$\frac{19}{24}$ in.	...	...	...	0·644	0·667	0·70
$1\frac{5}{48}$ in.	...	...	...	0·644	0·663	0·69
$1\frac{7}{12}$ in.	...	...	0·624	0·643	0·661	...
2 in.	...	...	0·625	0·643	0·660	...
$2\frac{9}{24}$ in.	...	0·611	0·627	0·642	...	...
$3\frac{1}{6}$ in.	...	0·612	0·628	0·640	...	...
4 in.	...	0·613	0·630	0·638	...	...
$4\frac{3}{4}$ in.	0·592	0·614	0·631	...	...	...
6 in.	0·597	0·615	0·631	...	...	...
8 in.	0·599	0·616	0·631	...	...	...
1 ft.	0·601	0·616	...	...	...	...
1 ft. 8 in.	0·603	0·617	...	...	...	...
3 ft. $3\frac{1}{2}$ in.	0·605	...	...	...	...	...

TABLE II.—COEFFICIENT OF DISCHARGE OVER WEIRS, GIVEN BY PONCELET AND LESBROS. See Part III., page 53.

Height over weir......	$\frac{19}{48}$ in.	$\frac{19}{24}$ in.	$1\frac{5}{48}$ in.	$1\frac{7}{12}$ in.	$2\frac{9}{24}$ in.	$3\frac{1}{6}$ in.
Value of coefficient...	0·424	0·417	0·412	0·407	0·401	0·397
Height over orifice ...	4 in.	6 in.	8 in.	$8\frac{2}{3}$ in.		
Value of coefficient...	0·395	0·393	0·390	0·385		

III.—Loss of Head by Flow through Pipes, or Inclination ary to maintain the Velocity and Discharge given in Table; uantity being expressed in Cubic Feet, and the Loss of Head t Lineal.

Diameter, 0·5 in. Area, 0·1963 in.		Diameter, 0·625 in. Area, 0·3068 in.		
Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
0·001363	0·012230	1·000	0·002131	0·009784
0·001476	0·014037	1·083	0·002308	0·011230
0·001589	0·015952	1·166	0·002484	0·012762
0·001704	0·018005	1·250	0·002663	0·014404
0·001817	0·020136	1·333	0·002840	0·016109
0·001930	0·022376	1·416	0·003017	0·017901
0·002044	0·024750	1·500	0·003196	0·019800
0·002158	0·027202	1·583	0 003372	0·021761
0·002271	0·029754	1·666	0·003549	0·023804
0·002385	0·032446	1·750	0·003728	0·025957
0·002498	0·035205	1·833	0·003904	0·028164
0·002612	0·038064	1·916	0·004082	0·030454
0·002726	0 041071	2·000	0·004261	0·032857
0·002839	0·044135	2·083	0·004438	0·035308
0·002952	0·047304	2·166	0·004615	0·037843
0·003067	0·050608	2·250	0·004794	0·040486
0·003180	0·053974	2·333	0·004970	0·043179
0·003293	0·057436	2·416	0·005147	0·045948
0·003407	0·061047	2·500	0·005326	0·048837
0·003521	0·064708	2·583	0·005503	0·051767
0·003634	0·068466	2·666	0·005680	0·054773
0·003748	0·072372	2·750	0·005859	0·057898
0·003861	0·076327	2·833	0·006035	0·061061
0·003975	0·080379	2·916	0·006213	0·064303
0·004089	0·084584	3·000	0·006392	0·067667

TABLE III.—*continued.*

Diameter, 0·750 in. Area, 0·4417 in.			Diameter, 0·875 in. Area, 0·6013 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of h per fo
1·000	0·003067	0·008153	1·000	0·004176	0·006
1·083	0·003322	0·009358	1·083	0·004522	0·008
1·166	0·003576	0·010634	1·166	0·004868	0·009
1·250	0·003834	0·012003	1·250	0·005219	0·010
1·333	0·004088	0·013424	1·333	0·005566	0·011
1·416	0·004343	0·014917	1·416	0·005912	0·012
1·500	0·004601	0·016500	1·500	0·006263	0·014
1·583	0·004855	0·018134	1·583	0·006610	0·015
1·666	0·005110	0·019836	1·666	0·006957	0·017
1·750	0·005367	0·021631	1·750	0·007307	0·018
1·833	0·005622	0·023470	1·833	0·007654	0·020
1·916	0·005877	0·025378	1·916	0·008000	0·021
2·000	0·006134	0·027381	2·000	0·008351	0·023
2·083	0·006389	0·029422	2·083	0·008698	0·025
2·166	0·006644	0·031536	2·166	0·009044	0·027
2·250	0·006901	0·033738	2·250	0·009395	0·028
2·333	0·007155	0·035982	2·333	0·009742	0·030
2·416	0·007411	0·038290	2·416	0·010088	0·032
2·500	0·007668	0·040698	2·500	0·010439	0·034
2·583	0·007923	0·043139	2·583	0·010786	0·036
2·666	0·008177	0·045644	2·666	0·011132	0·039
2·750	0·008435	0·048248	2·750	0·011483	0·041
2·833	0·008690	0·050884	2·833	0·011830	0·043
2·916	0·008944	0·053586	2·916	0·012176	0·045
3·000	0·009202	0·056389	3·000	0·012527	0·048

TABLE III.—*continued.*

ameter, 1·000 in. rea, ·7854 in.		Diameter, 1·250 in. Area, 1·2271 in.		
Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
0·005454	0·006115	1·000	0·008522	0·004892
0·005907	0·007019	1·083	0·009228	0·005615
0·006359	0·007976	1·166	0·009936	0·006381
0·006817	0·009002	1·250	0·010652	0·007202
0·007270	0·010068	1·333	0·011359	0·008054
0·007723	0·011188	1·416	0·012066	0·008950
0·008181	0·012375	1·500	0·012782	0·009900
0·008634	0·013600	1·583	0·013489	0·010880
0·009086	0·014877	1·666	0·014197	0·011902
0·009544	0·016223	1·750	0·014913	0·012978
0·009997	0·017603	1·833	0·015620	0·014082
0·010450	0·019032	1·916	0·016327	0·015227
0·010908	0·020535	2·000	0·017043	0·016428
0·011361	0·022067	2·083	0·017750	0·017654
0·011813	0·023652	2·166	0·018458	0·018921
0·012272	0·025304	2·250	0·019173	0·020243
0·012724	0·026987	2·333	0·019881	0·021589
0·013177	0·028718	2·416	0·020588	0·022974
0·013635	0·030523	2·500	0·021304	0·024419
0·014088	0·032354	2·583	0·022011	0·025883
0·014540	0·034233	2·666	0·022719	0·027386
0·014999	0·036186	2·750	0·023434	0·028949
0·015451	0·038163	2·833	0·024142	0·030531
0·015904	0·040189	2·916	0·024849	0·03215
0·016362	0·042292	3·000	0·025565	0·033

TABLE III.—*continued.*

Diameter, 1·500 in. Area, 1·7671 in.			Diameter, 1·750 in. Area, 2·4052 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of h per foot
1·000	0·012271	0·004077	1·000	0·016703	0·0034
1·083	0·013290	0·004679	1·083	0·018089	0·0040
1·166	0·014309	0·005317	1·166	0·019475	0·0045
1·250	0·015339	0·006002	1·250	0·020878	0·0051
1·333	0·016358	0·006712	1·333	0·022265	0·0057
1·416	0·017376	0·007458	1·416	0·023651	0·0063
1·500	0·018407	0·008250	1·500	0·025054	0·0070
1·583	0·019426	0·009067	1·583	0·026440	0·0077
1·666	0·020444	0·009918	1·666	0·027827	0·0085
1·750	0·021475	0·010815	1·750	0·029230	0·0092
1·833	0·022494	0·011735	1·833	0·030616	0·0100
1·916	0·023512	0·012689	1·916	0·032003	0·0108
2·000	0·024543	0·013690	2·000	0·033406	0·0117
2·083	0·025562	0·014711	2·083	0·034792	0·0126
2·166	0·026580	0·015768	2·166	0·036178	0·0135
2·250	0·027610	0·016869	2·250	0·037581	0·0144
2·333	0·028629	0·017991	2·333	0·038968	0·0154
2·416	0·029648	0·019145	2·416	0·040354	0·0164
2·500	0·030679	0·020349	2·500	0·041757	0·0174
2·583	0·031697	0·021569	2·583	0·043143	0·0184
2·666	0·032716	0·022822	2·666	0·044530	0·0195
2·750	0·033746	0·024124	2·750	0·045933	0·0206
2·833	0·034765	0·025442	2·833	0·047319	0·0218
2·916	0·035783	0·026793	2·916	0·048705	0·0229
3·000	0·036814	0·028194	3·000	0·050108	0·0241

TABLE III.—*continued.*

	Diameter, 2·000 in. Area, 3·1416 in.		Diameter, 2·500 in. Area, 4·9087 in.		
ty l.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
0	0·021817	0·003057	1·000	0·034088	0·002446
3	0·023627	0·003509	1·083	0·036917	0·002807
6	0·025438	0·003988	1·166	0·039747	0·003190
0	0·027271	0·004501	1·250	0·042610	0·003601
3	0·029081	0·005034	1·333	0·045439	0·004027
6	0·030892	0·005594	1·416	0·048269	0·004475
0	0·032725	0·006188	1·500	0·051132	0·004950
3	0·034536	0·006800	1·583	0·053962	0·005440
6	0·036347	0·007438	1·666	0·056791	0·005951
0	0·038179	0·008111	1·750	0·059654	0·006489
3	0·039990	0·008801	1·833	0·062484	0·007041
6	0·041800	0·009517	1·916	0·065313	0·007613
0	0·043634	0·010268	2·000	0·068176	0·008214
3	0·045444	0·011034	2·083	0·071006	0·008827
6	0·047255	0·011826	2·166	0·073835	0·009460
0	0·049087	0·012652	2·250	0·076698	0·010121
3	0·050898	0·013493	2·333	0·079528	0·010795
6	0·052709	0·014359	2·416	0·082357	0·011487
0	0·054542	0·015262	2·500	0·085220	0·012209
3	0·056352	0·016177	2·583	0·088050	0·012941
6	0·058163	0·017116	2·666	0·090879	0·013693
0	0·059996	0·018093	2·750	0·093742	0·014475
3	0·061807	0·019082	2·833	0·096572	0·015265
6	0·063617	0·020095	2·916	0·099401	0·016076
0	*0·065450*	*0·021146*	3·000	0·102264	0·016916

TABLE III.—*continued.*

Diameter, 3·000 in. Area, 7·0686 in.			Diameter, 3·5000 in. Area, 9·6211 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of [illegible] per fo[illegible]
1·000	0·049087	0·002038	1·000	0·066813	0·001[illegible]
1·083	0·053162	0·002339	1·083	0·072359	0·002[illegible]
1·166	0·057236	0·002658	1·166	0·077904	0·002[illegible]
1·250	0·061359	0·003001	1·250	0·083516	0·002[illegible]
1·333	0·065433	0·003356	1·333	0·089062	0·002[illegible]
1·416	0·069508	0·003729	1·416	0·094607	0·003[illegible]
1·500	0·073631	0·004125	1·500	0·100220	0·003[illegible]
1·583	0·077705	0·004533	1·583	0·105765	0·003[illegible]
1·666	0·081780	0·004959	1·666	0·111311	0·004[illegible]
1·750	0·085903	0·005408	1·750	0·116923	0·004[illegible]
1·833	0·089977	0·005867	1·833	0·122468	0·005[illegible]
1·916	0·094052	0·006344	1·916	0·128014	0·005[illegible]
2·000	0·098175	0·006845	2·000	0·133626	0·005[illegible]
2·083	0·102249	0·007356	2·083	0·139172	0·006[illegible]
2·166	0·106323	0·007884	2·166	0·144717	0·006[illegible]
2·250	0·110447	0·008435	2·250	0·150330	0·007[illegible]
2·333	0·114521	0·008996	2·333	0·155875	0·007[illegible]
2·416	0·118595	0·009572	2·416	0·161420	0·008[illegible]
2·500	0·122719	0·010174	2·500	0·167033	0·008[illegible]
2·583	0·126793	0·010784	2·583	0·172578	0·009[illegible]
2·666	0·130867	0·011411	2·666	0·178124	0·009[illegible]
2·750	0·134990	0·012062	2·750	0·183736	0·010[illegible]
2·833	0·139065	0·012721	2·833	0·189282	0·010[illegible]
2·916	0·143139	0·013396	2·916	0·194827	0·011[illegible]
3·000	0·147262	0·014097	3·000	0·200439	0·012[illegible]

TABLE III.—*continued.*

Diameter, 4·000 in. Area, 12·566 in.			Diameter, 4·500 in. Area, 15·904 in.		
ity r nd.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
00	0·087264	0·001529	1·000	0·110444	0·001358
83	0·094507	0·001755	1·083	0·119611	0·001559
66	0·101750	0·001994	1·166	0·128778	0·001772
50	0·109080	0·002250	1·250	0·138055	0·002000
33	0·116323	0·002517	1·333	0·147222	0·002235
16	0·123566	0·002797	1·416	0·156390	0·002485
00	0·130896	0·003094	1·500	0·165667	0·002747
83	0·138139	0·003400	1·583	0·174834	0·003019
66	0·145382	0·003719	1·666	0·184000	0·003305
50	0·152712	0·004056	1·750	0·193278	0·003600
33	0·159954	0·004401	1·833	0·202445	0·003908
16	0·167198	0·004758	1·916	0·211611	0·004228
00	0·174528	0·005134	2·000	0·220889	0·004559
83	0·181770	0·005517	2·083	0·230056	0·004899
66	0·189014	0·005913	2·166	0·239222	0·005250
50	0·196344	0·006326	2·250	0·248500	0·005617
33	0·203587	0·006747	2·333	0·257667	0·005991
16	0·210830	0·007179	2·416	0·266834	0·006375
00	0·218160	0·007631	2·500	0·276111	0·006776
83	0·225403	0·008088	2·583	0·285278	0·007182
66	0·232646	0·008558	2·666	0·294444	0·007600
50	0·239976	0·009047	2·750	0·303722	0·008039
33	0·247218	0·009541	2·833	0·312889	0·008477
16	0·254461	0·010047	2·916	0·322056	0·008928
00	0·261792	0·010573	3·000	0·331333	0·009394

TABLE III.—*continued.*

Diameter, 5·000 in. Area, 19·635 in.			Diameter, 6·000 in. Area, 28·274 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of he per foot.
1·000	0·136354	0·001223	1·000	0·196347	0·0010
1·083	0·147671	0·001404	1·083	0·212644	0·0011
1·166	0·158989	0·001595	1·166	0·228941	0·0013
1·250	0·170443	0·001800	1·250	0·245434	0·0015
1·333	0·181760	0·002014	1·333	0·261731	0·0016
1·416	0·193077	0·002237	1·416	0·278028	0·0018
1·500	0·204531	0·002475	1·500	0·294521	0·0020
1·583	0·215848	0·002720	1·583	0·310818	0·0022
1·666	0·227166	0·002975	1·666	0·327114	0·0024
1·750	0·238620	0·003244	1·750	0·343608	0·0027
1·833	0·249937	0·003520	1·833	0·359904	0·0029
1·916	0·261254	0·003807	1·916	0·376201	0·0031
2·000	0·272708	0·004107	2·000	0·392694	0·0034
2·083	0·284025	0·004413	2·083	0·408991	0·0036
2·166	0·295343	0·004730	2·166	0·425288	0·0039
2·250	0·306797	0·005061	2·250	0·441781	0·0042
2·333	0·318114	0·005397	2·333	0·458078	0·0044
2·416	0·329432	0·005743	2·416	0·474375	0·0047
2·500	0·340885	0·006105	2·500	0·490868	0·0050
2·583	0·352203	0·006471	2·583	0·507165	0·0053
2·666	0·363520	0·006846	2·666	0·523462	0·0057
2·750	0·374974	0·007237	2·750	0·539955	0·0060
2·833	0·386291	0·007633	2·833	0·556251	0·0063
2·916	0·397609	0·008038	2·916	0·572548	0·0066
3·000	0·409062	0·008458	3·000	0·589041	0·0070

TABLE III.—*continued.*

Diameter, 7·000 in. Area, 38·484 in.			Diameter, 8·000 in. Area, 50·265 in.		
city r nd.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
00	0·267250	0·000873	1·000	0·349062	0·000764
83	0·289432	0·001002	1·083	0·378035	0·000877
66	0·311613	0·001139	1·166	0·407007	0·000997
50	0·334062	0·001286	1·250	0·436328	0·001125
33	0·356244	0·001438	1·333	0·465300	0·001258
16	0·378426	0·001598	1·416	0·494272	0·001398
00	0·400875	0·001767	1·500	0·523594	0·001547
83	0·423057	0·001942	1·583	0·552566	0·001700
66	0·445238	0·002125	1·666	0·581538	0·001859
50	0·467687	0·002317	1·750	0·610859	0·002028
33	0·489869	0·002514	1·833	0·639831	0·002200
16	0·512051	0·002719	1·916	0·668804	0·002379
00	0·534500	0·002933	2·000	0·698125	0·002567
83	0·556682	0·003152	2·083	0·727097	0·002758
66	0·578863	0·003378	2·166	0·756069	0·002956
50	0·601312	0·003614	2·250	0·785390	0·003163
33	0·623494	0·003855	2·333	0·814363	0·003373
16	0·645676	0·004102	2·416	0·843335	0·003589
00	0·668125	0·004360	2·500	0·872656	0·003815
83	0·690307	0·004621	2·583	0·901628	0·004044
66	0·712488	0·004889	2·666	0·930600	0·004279
50	0·734937	0·005169	2·750	0·959921	0·004523
33	0·757119	0·005451	2·833	0·988894	0·004770
16	0·779301	0·005740	2·916	1·017866	0·005024
00	0·801750	0·006041	3·000	1·047187	0·005286

TABLE III.—*continued.*

Diameter, 9·000 in. Area, 63·617 in.			Diameter, 10·000 in. Area, 78·540 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of he per foot.
1·000	0·441785	0·000679	1·000	0·545417	0·00061
1·083	0·478453	0·000779	1·083	0·590686	0·0007
1·166	0·515121	0·000886	1·166	0·635956	0·0007
1·250	0·552231	0·001000	1·250	0·681771	0·0009
1·333	0·588899	0·001117	1·333	0·727040	0·0010
1·416	0·625567	0·001242	1·416	0·772310	0·0011
1·500	0·662677	0·001374	1·500	0·818125	0·0012
1·583	0·699345	0·001509	1·583	0·863394	0·0013
1·666	0·736013	0·001651	1·666	0·908664	0·0014
1·750	0·773123	0·001800	1·750	0·954479	0·0016
1·833	0·809791	0·001954	1·833	0·999749	0·0017
1·916	0·846459	0·002114	1·916	1·045018	0·0019
2·000	0·883570	0·002279	2·000	1·090834	0·0020
2·083	0·920237	0·002449	2·083	1·136103	0·0022
2·166	0·956906	0·002625	2·166	1·181372	0·0023
2·250	0·994016	0·002809	2·250	1·227187	0·0025
2·333	1·030684	0·002995	2·333	1·272457	0·0026
2·416	1·067352	0·003187	2·416	1·317727	0·00287
2·500	1·104462	0·003388	2·500	1·363542	0·00305
2·583	1·141130	0·003591	2·583	1·408811	0·00323
2·666	1·177798	0·003800	2·666	1·454081	0·00342
2·750	1·214908	0·004019	2·750	1·499896	0·00361
2·833	1·251576	0·004238	2·833	1·545165	0·00381
2·916	1·288244	0·004464	2·916	1·590435	0·00401
3·000	1·325354	0·004697	3·000	1·636250	0·0042

TABLE III.—*continued.*

Diameter, 11·000 in. Area, 95·033 in.			Diameter, 12·000 in. Area, 113·097 in.		
city r nd.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
00	0·659952	0·000556	1·000	0·785396	0·000509
83	0·714727	0·000638	1·083	0·850584	0 000585
66	0·769503	0·000725	1·166	0 915771	0·000664
50	0·824940	0·000818	1·250	0·981745	0·000750
33	0·879715	0·000915	1·333	1·046933	0 000839
16	0·934491	0·001017	1·416	1·112120	0·000932
00	0·989927	0·001125	1·500	1·178094	0·001031
83	1·044703	0·001236	1·583	1·243282	0·001133
66	1·099479	0 001352	1·666	1·308469	0·001239
50	1·154915	0·001475	1·750	1·374443	0·001352
33	1·209691	0 001600	1·833	1·439630	0·001467
16	1·264467	0·001730	1·916	1·504818	0·001586
00	1·319903	0·001867	2·000	1·570792	0·001711
83	1·374679	0·002006	2·083	1·635979	0·001839
66	1·429455	0·002150	2·166	1·701167	0·001971
50	1·484892	0·002300	2·250	1·767140	0·002108
33	1·539667	0·002453	2·333	1·832328	0·002249
16	1·594442	0·002611	2·416	1·897516	0·002393
00	1·649878	0·002775	2·500	1·963490	0·002543
83	1·704654	0·002941	2·583	2·028677	0·002696
66	1·759430	0·003112	2·666	2·093865	0·002853
50	1·814866	0·003290	2·750	2·159838	0·003015
33	1·869642	0·003470	2·833	2·225026	0·003180
16	1·924418	0·003654	2·916	2·290214	0 003349
00	1·979854	0·003845	3·000	2·356187	0·003524

TABLE III.—*continued.*

Diameter, 17·000 in. Area, 226·980 in.			Diameter, 18·000 in. Area, 254·469 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	1·576250	0·000359	1·000	1·767146	0·000339
1·083	1·707079	0·000413	1·083	1·913819	0·000397
1·166	1·837907	0·000469	1·166	2·060492	0·000443
1·250	1·970312	0·000529	1·250	2·208932	0·000500
1·333	2·101141	0·000592	1·333	2·355605	0·000559
1·416	2·231970	0·000658	1·416	2·502278	0·000621
1·500	2·364375	0·000728	1·500	2·650719	0·000687
1·583	2·495204	0·000800	1·583	2·797392	0·000755
1·666	2·626032	0·000875	1·666	2·944065	0·000825
1·750	2·758437	0·000954	1·750	3·092505	0·000900
1·833	2·889266	0·001035	1·833	3·239178	0·000978
1·916	3·020095	0·001120	1·916	3·385852	0·001056
2·000	3·152500	0·001208	2·000	3·534292	0·001140
2·083	3·283329	0·001298	2·083	3·680965	0·001225
2·166	3·414157	0·001391	2·166	3·827638	0·001312
2·250	3·546562	0·001489	2·250	3·976078	0·001404
2·333	3·677391	0·001588	2·333	4·122751	0·001498
2·416	3·808220	0·001689	2·416	4·269424	0·001594
2·500	3·940625	0·001796	2·500	4·417864	0·001694
2·583	4·071454	0·001903	2·583	4·564538	0·001795
2·666	4·202282	0·002014	2·666	4·711210	0·001900
2·750	4·334687	0·002129	2·750	4·859651	0·002009
2·833	4·465516	0·002245	2·833	5·006324	0·002119
2·916	4·596345	0·002364	2·916	5·152997	0·002232
3·000	4·728750	0·002488	3·000	5·301437	0·002348

TABLE III.—*continued.*

Diameter, 21·000 in. Area, 346·361 in.		Diameter, 24·000 in. Area, 452·390 in.		
Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
2·405285	0·000291	1·000	3·141597	0·000254
2·604923	0·000334	1·083	3·402350	0·000292
2·804562	0·000379	1·166	3·663102	0·000332
3·006606	0·000428	1·250	3·926996	0·000375
3·206244	0·000479	1·333	4·187749	0·000419
3·405883	0·000532	1·416	4·448502	0·000466
3·607927	0·000589	1·500	4·712396	0·000516
3·807566	0·000647	1·583	4·973148	0·000567
4·007204	0·000703	1·666	5·233901	0·000620
4·209248	0·000772	1·750	5·497795	0·000676
4·408887	0·000837	1·833	5·758548	0·000733
4·608525	0·000906	1·916	6·019300	0·000793
4·810569	0·000977	2·000	6·283194	0·000855
5·010208	0·001050	2·083	6·543947	0 000919
5·209847	0·001155	2·166	6·804699	0·000985
5·411891	0·001204	2·250	7·068594	0·001054
5·611529	0·001284	2·333	7·329346	0·001124
5·811168	0·001366	2·416	7·590099	0·001196
6·013212	0·001452	2·500	7·853993	0·001272
6·212850	0·001539	2·583	8·114745	0·001348
6·412488	0 001629	2·666	8 375498	0·001426
6·614533	0·001722	2·750	8·639392	0·001508
6·814172	0·001816	2·833	8·900145	0·001590
7·013810	0·001912	2·916	9·160897	0·001674
7·215854	*0·002112*	3·000	9·424792	0·001762

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